THIRTY-SEVENTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

1951

INCLUDING TECHNICAL REPORTS
NOS. 1003 to 1058

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Letter of Transmittal

To the Congress of the United States:

In compliance with the provisions of the act of March 3, 1915, as amended, establishing the National Advisory Committee for Aeronautics, I transmit herewith the Thirty-seventh Annual Report of the Committee covering the fiscal year 1951.

HARRY S. TRUMAN.

THE WHITE HOUSE,
JANUARY 28, 1952.

Letter of Submittal

National Advisory Committee for Aeronautics
Washington, D. C., *November 15, 1951.*

Dear Mr. President: In compliance with the act of Congress approved March 3, 1915, as amended (U. S. C. 1946, title 50, sec. 153), I have the honor to submit herewith the Thirty-seventh Annual Report of the National Advisory Committee for Aeronautics covering the fiscal year 1951.

The development of new types of aircraft slowed materially since the end of World War II but, since Korea, progress is now rapidly accelerating. The magnitude of the military effort required to check world-wide aggression makes it evident that America's aircraft must be superior in performance and military effectiveness to those of any other nation.

The Committee seeks, through timely and adequate research, to assure the success of the expanding aircraft program. The Committee believes that in order to support the military effort effectively, its scope of operations should be increased to the extent that availability of scientific manpower will permit.

Respectfully submitted.

Jerome C. Hunsaker,
Chairman.

The President,
The White House, Washington, D. C.

National Advisory Committee for Aeronautics

Headquarters, 1724 F Street NW., Washington 25, D. C.

Created by act of Congress approved March 3, 1915, for the supervision and direction of the scientific study of the problems of flight (U. S. Code, title 50, sec. 151). Its membership was increased from 12 to 15 by act approved March 2, 1929, and to 17 by act approved May 25, 1948. The members are appointed by the President, and serve as such without compensation.

TECHNICAL COMMITTEES

AERODYNAMICS
POWER PLANT FOR AIRCRAFT
AIRCRAFT CONSTRUCTION
OPERATING PROBLEMS
INDUSTRY CONSULTING

Coordination of Research Needs of Military and Civil Aviation
Preparation of Research Programs
Allocation of Problems
Prevention of Duplication
Consideration of Inventions

LANGLEY AERONAUTICAL LABORATORY
Langley Field, Va.

AMES AERONAUTICAL LABORATORY
Moffett Field, Calif.

LEWIS FLIGHT PROPULSION LABORATORY
Cleveland Airport, Cleveland, Ohio

Conduct, under unified control, for all agencies, of scientific research on the fundamental problems of flight

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OFFICE OF AERONAUTICAL INTELLIGENCE
Washington, D. C.

Collection, classification, compilation, and dissemination of scientific and technical information on aeronautics

THIRTY-SEVENTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C., *November 15, 1951.*

To the Congress of the United States:

In accordance with the act of Congress, approved March 3, 1915 (U. S. C. title 50, sec. 151), which established the National Advisory Committee for Aeronautics, the Committee submits its thirty-seventh annual report for the fiscal year 1951.

The United States is engaged in expanding military aviation to levels never before reached except in the midst of a major war. In Korea, our military aircraft are engaged in combat with airplanes of an unfriendly nation evidently able to build military aircraft of increasing capabilities. In this environment, the NACA is responsible for conducting an adequate program of scientific research to open the way for the design of aircraft and missiles of superior performance.

Since World War II the pace of technical development has increased. Until then, improvement in aircraft performance as a result of the application of scientific research proceeded at what now seems to be a relatively slow and orderly rate. Modest increases in speed, climb, range, or altitude were set as reasonable goals. Compressibility effects at high speeds were just beginning to be encountered and indicated a formidable barrier near the velocity of sound. This barrier has been found by research and experiment to be less formidable than supposed, and we now see the possibility of radical gains in airplane performance that are of great military significance. Such gains are also attainable by a potential enemy.

The increased complexity of modern high performance aircraft results in greatly increased costs, whether measured in manpower or dollars, and places more at stake in the success or failure of the research upon which superior performance is predicated. In view of the magnitude of the national effort to build up air power adequate to our national security, scientific research should proceed on a corresponding scale.

In the years immediately following World War II in appreciation of the probable significance to national security of applications of new knowledge of supersonic aerodynamics and jet propulsion, the President and the Congress supported the NACA in an intensive program of fundamental scientific studies in these fields of aeronautical science. There was an urgent need to overcome a serious deficiency of basic information resulting from wartime concentration of research teams on immediate problems associated with the improvement of airplanes in service. Only by concentration on fundamentals may we expect to find leads to radically new developments which should pay off in the design of future aircraft. We do not know how long the present period of tension will last nor do we know what discoveries an enemy may make.

In addition, the Committee must not neglect less spectacular research to provide engineering information essential to the safety and economy of aircraft of all types, both civil and military. In this, the NACA has responsibility for the scientific study and practical solution of current problems, as crystallized in the discussions of our several subcommittees of experts. These subcommittees include designers, users, and research scientists. Research initiated to solve a current problem can be readily translated into practice. Such research, for example, makes possible an increase in thrust of current production engines and improved performance of the next lot of airplanes. The need for extended work in this area has been reflected in our budget estimates.

The military research and development program has been increased threefold, but to date the funds and manpower authorized for NACA have not expanded to support adequately the military effort. Therefore, the Committee urges an expansion in NACA effort to the extent that availability of scientific manpower will permit.

Presently, emphasis is on the military applications of research, but many of the results of NACA research effort are of value to civil aviation, as for example the work on ice prevention, fire prevention, effects of atmospheric turbulence, and work on aircraft stability and control. Much research for the improvement of military aircraft is extended to obtain data needed by those responsible for the design, operation, or regulation of civil aircraft.

During the current year the Committee completed the installation of a transonic ventilated throat in the 16-foot wind tunnel at the Langley Aeronautical Laboratory. This installation is based on an invention by members of the NACA staff and is considered to be of exceptional importance because it permits model airplane tests at transonic air speeds in wind tunnels, hitherto impossible because of the choking of the conventional wind tunnel as the air speed approaches the velocity of sound.

In the formulation of its research programs, the Committee has been materially assisted by some 400 members of its 26 technical committees. These members include scientists from universities, engineers from industry, and experts from the civil and military agencies of the Government. The Committee continues to enjoy the loyal and effective support of its civil service staff in the execution of its policies and directives.

Parts I, II, and III of this annual report present a résumé of the unclassified scientific activities of the Committee, a description of the Committee's organization and membership, and the financial report for the fiscal year 1951.

Respectfully submitted.

Jerome C. Hunsaker,
Chairman

Part I—TECHNICAL ACTIVITIES

RESEARCH ORGANIZATION AND PROCEDURES

COMMITTEE LABORATORIES

Research of the National Advisory Committee for Aeronautics is conducted largely at its three laboratories—Langley Aeronautical Laboratory, Langley Field, Va.; Ames Aeronautical Laboratory, Moffett Field, Calif.; and Lewis Flight Propulsion Laboratory, Cleveland, Ohio. A subsidiary station is located at Wallops Island, Va., as a branch of the Langley Laboratory for conducting research on models in flight in the transonic and supersonic speed ranges. At Edwards, Calif., is located the NACA High-Speed Flight Research Station for research on transonic and supersonic airplanes in flight. The total number of employees, both technical and administrative, at these five stations and headquarters in Washington was 7,705 at the end of the fiscal year 1951.

TECHNICAL COMMITTEES AND RESEARCH COORDINATION

In carrying out its function of coordinating aeronautical research the Committee is assisted by a group of technical committees and subcommittees. The members of these committees are chosen for their particular knowledge in a specific field of aeronautics. They are selected from other Government agencies concerned with aviation including the Department of Defense, from the aircraft and air transport industries, and from scientific and educational institutions. These committees provide for the interchange of ideas and prevention of research duplication except where parallel efforts are desired. There are four technical committees under the National Advisory Committee for Aeronautics:

1. Committee on Aerodynamics.
2. Committee on Power Plants for Aircraft.
3. Committee on Aircraft Construction.
4. Committee on Operating Problems.

Each committee is supported by three to eight technical subcommittees.

In addition to the four technical committees, there is an Industry Consulting Committee established to assist the main Committee in formulation of general policy. Membership of this Committee, as well as the technical committees and subcommittees, is listed in part II of this report.

Research coordination is further effected through discussions between Committee technical personnel and the research staffs of the aviation industry, educational and scientific organizations, and other aeronautical agencies. The Research Coordination Office is assisted by a west coast representative who maintains close contact with the aeronautical research and engineering staffs of that geographical area.

RESEARCH SPONSORED IN SCIENTIFIC AND RESEARCH INSTITUTIONS

For the 1951 fiscal year the NACA continued to make use of the unique research talents and facilities of universities and other nonprofit scientific institutions to find solutions for aeronautical problems. Both research proposals and the results from investigations have been carefully reviewed to maintain the quality of this part of the NACA program, and reports of the useful results of the sponsored research have been given the same wide distribution as other NACA reports.

The diversity of this sponsored research is indicated by the fact that 19 of the NACA technical subcommittees reviewed proposals for or the results of such investigations during the past year and that 48 reports of sponsored research were released. The technical aspects of the program are included with the descriptions of work under the various technical sections.

During the 1951 fiscal year the following institutions participated in the contract research program:

National Bureau of Standards, Forest Products Laboratory, Armour Research Foundation, Battelle Memorial Institute, Polytechnic Institute of Brooklyn, Brown University, California Institute of Technology, University of California, University of California at Los Angeles, Carnegie Institute of Technology, University of Cincinnati, Cornell University, University of Florida, Georgia Institute of Technology, Harvard University, Illinois Institute of Technology, University of Illinois, Iowa State College, Johns Hopkins University, Massachusetts Institute of Technology, University of Michigan, Mount Washington Observatory, New York University, University of Notre Dame, Ohio State University, Pennsylvania State College, Princeton University, Purdue University, Stanford University, Stevens Institute of Technology, Syracuse University, Texas Agricultural and Mechanical College, University of Virginia, and University of Washington.

RESEARCH INFORMATION

Research results obtained in the Committee's laboratories and through research contracts are distributed in the form of Committee publications. Formal Reports, printed by the Government Printing Office, contain unclassified information and are available to the general public from the Superintendent of Documents. Technical Notes, released by the Committee in limited numbers, also contain unclassified research results of a more or less interim nature and are distributed to interested organizations throughout the country. Frequently, research results which will ultimately be published in Report form are issued initially as Technical Notes in the interest of speedy dissemination of data to American technical people and organizations. Translations of foreign material are issued in the form of Technical Memorandums.

In addition to unclassified publications the Committee prepares a large number of reports containing classified research information. For reasons of national security, these reports are controlled in their circulation. From time to time the classified reports are examined to determine whether it is in the national interest to declassify them. If it is found desirable to declassify the reports, they may be published as unclassified papers.

Another important means of transmitting quickly and efficiently the latest information in a particular field of research directly to designers and engineers working in that field is the holding of technical conferences from time to time at an appropriate NACA laboratory. Several conferences of this nature were held during the past year.

The Office of Aeronautical Intelligence was established in 1918 as an integral part of the Committee's activities. Its functions are the collection and classification of technical knowledge on the subject of aeronautics, including the results of research and experimental work conducted in all parts of the world, and its dissemination to the Department of Defense, aircraft manufacturers, educational institutions, and other interested people. American and foreign reports obtained are analyzed, classified, and brought to the attention of the proper persons through the medium of public and confidential bulletins.

AERONAUTICAL INVENTIONS

By act of Congress, approved July 2, 1926 (U. S. C. title 10, sec. 310–r), an Aeronautical Patents and Design Board was established consisting of the Assistant Secretaries for Air of the Departments of War, Navy, and Commerce. In accordance with that act as amended by an act, approved March 3, 1927, the National Advisory Committee for Aeronautics is charged with the function of analyzing and reporting upon the technical merits of aeronautical inventions and designs submitted to any agency of the Government. The Aeronautical Patents and Design Board is authorized, upon the favorable recommendation of the Committee to "determine whether the use of the design by the Government is desirable or necessary and evaluate the design and fix its worth to the United States in an amount not to exceed $75,000."

Recognizing its obligation to the public in this respect the Committee has continued to accord to all correspondence on such matters full consideration. All proposals received have been carefully analyzed and evaluated and the submitters have been advised concerning the probable merits of their suggestions. Many personal interviews have been granted inventors who visited the Committee's offices, and technical information has been supplied when requested.

* * * * *

The following detailed summary of unclassified research, completed during the fiscal year 1951, is organized to reflect the areas of research over which each technical committee and related subcommittee has cognizance.

AERODYNAMIC RESEARCH

During the past year there has been an increase in research directed specifically at the problems of high-speed airplanes and guided missiles. Aerodynamic research to permit efficient operation of airplanes at transonic speeds has continued to receive special emphasis, and information has been obtained in this speed range from flights of special research airplanes, rocket-powered free-flight models, freely-falling bodies, and from very small models on wind-tunnel bumps or by the wing-flow method in flight. There has, however, been a serious need for techniques to permit detailed systematic large-scale experiments to be made in wind tunnels through the speed of sound. As a result of extensive research on wind-tunnel design, suitable techniques have been developed, and the Langley 8-foot and 16-foot wind tunnels were modified to permit testing through the speed of sound. These modified tunnels are contributing to a better understanding of aerodynamic problems in the transonic speed range.

Theoretical and experimental research on high-speed airplane design problems has been directed generally at the establishment of technical information to permit the selection of the most efficient configurations for flights at transonic and supersonic speeds which will also have satisfactory flying characteristics at low speeds for landing and take-off. As the high-speed requirements increased, the landing requirements have become more difficult to meet and it has been necessary to continue research at low speeds on these problems.

In addition to studies of performance problems of guided missiles, considerable attention has been directed during the past year to the problems of stability and control. In this field particular emphasis has been placed on the cross-coupling effects experienced by various missile configurations and on automatic control problems.

The NACA is assisted in guiding the aerodynamic research activities of its laboratories by the Committee on Aerodynamics and its eight technical subcommittees. Results of the research which are most pertinent to the design and development of military airplanes and guided missiles are summarized and presented at technical conferences held during the year with the representatives of the military services and their contractors, in order to assist designers in making early application of these results.

In the sections which follow a description is given of some of the Committee's recent unclassified work in aerodynamics.

FLUID MECHANICS

Investigation of Airfoils at Low Speeds

Low-speed investigations of two-dimensional airfoils have been devoted to a large extent to the study of flow phenomena at high lifts and the development of methods for the improvement of high lift characteristics. Reported in Technical Note 2235 is an investigation of the boundary-layer and stalling characteristics of the NACA 64A–010 airfoil section in the Ames 7- by 10-foot wind tunnels. The results show the small region of separated flow or "bubble" near the leading edge, characteristic of airfoils with small leading-edge radii. At an angle of attack of 9.5° the separated flow failed to reattach to the surface, causing the stall. Since there was no turbulent separation at the trailing edge, the lift-curve peak was sharp and the stall occurred suddenly and with no warning.

An investigation was also conducted in the Ames 7- by 10-foot wind tunnels to determine the possibility of delaying the flow separation that occurs near the leading edge of the NACA 63_1–012 airfoil section and of improving its stalling characteristics by modifications of the contour near the leading edge. This study is reported in Technical Note 2228. The greatest improvement was obtained with modifications that incorporated an increase in camber and modifications to the leading-edge shape were more effective than drooped-nose flaps.

The results of a comprehensive investigation of the stalling characteristics of airfoil sections at low subsonic speeds in the Ames 7- by 10-foot wind tunnels have been summarized in Technical Note 2502. Several types of stall encountered with airfoils ranging in thickness from that for a slow, light airplane to that for a possible supersonic application are described in detail in conjunction with the characteristic flows in the boundary layer.

The increases in airplane lift-drag ratio associated with increasing aspect ratio are limited by the high profile-drag coefficients associated with the thick wing-root sections which are structurally necessary on wings of high aspect ratio. An investigation has therefore been made of NACA 64-series airfoils of 32- and 40-percent-chord thickness in the Langley low-turbulence tunnels to determine whether the high profile-drag coefficients of thick airfoils can be reduced by boundary-layer control through a single suction slot. The results obtained for the 32- and 40-percent-thick sections together with other available airfoil section data were used to calculate the characteristics of a number of hypothetical wings. These calculations indicate that the maximum attainable lift-drag ratio of structurally feasible wings and of the corresponding airplanes may be increased appreciably by the use of such thick wings with boundary-layer control. The results are presented in Technical Note 2405.

It has been found that in the higher ranges of landing speeds compressibility effects on maximum lift can become appreciable. As part of a program to explore this phenomenon, the effects of Mach number and Reynolds number on the maximum lift coefficient of a wing of NACA 66-series airfoil sections were determined in the Langley 19-foot pressure tunnel and are published in Technical Note 2251. The ranges of Mach number and Reynolds number extended up to 0.34 and 8.0 million, respectively. It was found that for a given value of Mach number, the values of maximum lift coefficient were increased when the Reynolds number was increased. For a given value of Reynolds number, an increase in Mach number at first caused only small reductions in maximum lift coefficient, but the reduction was large after the critical speed was exceeded.

Theoretical Investigations of Two-Dimensional Compressible Flows

Theoretical investigations of two-dimensional compressible flows are being continued with particular reference to the difficult transonic speed range. At the Langley Laboratory the Prandtl-Busemann small-perturbation method has been utilized to obtain the flow of a compressible fluid past a wave-shaped, infinitely long wall. When the essential assumption for transonic flow is introduced—that all Mach numbers in the region of flow are nearly unity—the expression for the velocity potential takes the form of a power series in the transonic similarity parameter. On the basis of this form of the solution, an attempt has been made to solve the nonlinear differential equation for transonic flow past a wavy wall. The results of this analysis exhibit clearly the inherent difficulties encountered in nonlinear flow problems. Nevertheless, the investigation has been carried in a rigorous manner to the point where the question of the existence or nonexistence of a mixed potential flow free of discontinuities can be settled by the behavior of a single power series in the transonic similarity parameter. The calculation of the coefficients of this dominant power series has been reduced to a routine computing problem by means of recursion formulas resulting from the solution of the differential equation and the boundary condition at the wall. One of the results of the analysis is the rigorous statement of a limit of applicability of the transonic similarity concept. The results are presented in TN 2383.

In Technical Note 2253 it is shown that it is possible to solve the Prandtl-Busemann iteration equations by means of the familiar concepts of a distribution of sources and sinks. The method is limited to the treatment of thin, sharp-nose, symmetric, two-dimensional profiles. An explicit expression is derived for the second-order velocity potential and velocity components, and a method for obtaining higher-order terms is indicated. The velocity at the surface of the Kaplan bump is evaluated to illustrate the method.

The relaxation method has been proposed as a means of calculating pressure distributions on two-dimensional bodies at high speeds, and a comparison is shown in Technical Note 2174 between the experimental pressure distribution for an NACA 0012 profile and the theoretical pressure distribution obtained by this method. The comparison showed good agreement at low speeds, but at higher Mach numbers the theoretical calculations indicated higher negative pressure coefficients than were obtained experimentally.

An integral method of calculating two-dimensional compressible flows past thin airfoils, with particular reference to the transonic speed range is presented in Technical Note 2130. By an appropriate choice of streamline curvature, this method permits the flow pattern about a thin airfoil to be calculated in a comparatively simple manner. The results presented include velocity distributions for various symmetric sections. Comparison with other theories and with available experimental data indicate at least qualitatively good agreement.

The transonic similarity law for two-dimensional flow, derived by von Karman, has been investigated by an iteration procedure and is presented in Technical Note 2191. The boundary condition of zero velocity normal to the body was satisfied at the body rather than near the body, as was done by von Karman. The results showed that the velocity potential can be expressed in terms of a similarity parameter and were in agreement with those of von Karman.

Theoretical investigations of two-dimensional compressible flows by several educational institutions under contract to the NACA are being continued. At the New York University an approximate method of solving the nonlinear differential equation for two-dimensional subsonic compressible flow by means of the variational method is being used. The general problem of steady irrotational flow past an arbitrary body is formulated and two examples have been carried out, namely, the flow past a circular cylinder and the flow past a thin curved surface. The variational method yields results of velocity and pressure distributions which compare well with those found by other methods.

The problem of two-dimensional flow behind a curved stationary shock wave has been considered analytically at the Massachusetts Institute of Technology. The method, which is presented in Technical Note 2364, assumes a given shock-wave shape, which automatically determines certain initial conditions on the flow variables; and the flow pattern, including any body shape, follows from the initial conditions. Approximate analytic expressions are found for the stream function in the subsonic region following the shock and, after the stream function is obtained, the flow density is determined by Bernoulli's equation, which connects the density with the derivatives of the stream function. The final solution can then be determined from the velocity field thus obtained.

Technical Note 2356 presents the results of a study, made at Cornell University, of the two-dimensional transonic flow past airfoils. The problem of constructing solutions for transonic flow over symmetric airfoils is treated and simplification of the mapping of the incompressible flow is emphasized. In the case of a symmetric Joukowski airfoil without circulation, the mapping is relatively simple, but the coefficients in the power series are difficult to evaluate. As a means of simplification, an approximate flow is used which differs only slightly from the exact incompressible one when the thickness is small. Flow with circulation is also considered by the same method.

At the Johns Hopkins University an investigation has been made of the transient behavior of an airfoil in supersonic flow due to pitching, flapping, and vertical gusts by means of the Fourier integral method. By using a convolution integral, the aerodynamic effect of any arbitrary motion of the airfoil can be determined, if the aerodynamic response of the airfoil to a step-function disturbance is known. As useful examples, the harmonically oscillating airfoil with different modes or degrees of freedom is analyzed for the complete time history, for the case in which the motion starts abruptly from rest. In carrying out the investigation, a new integral has been introduced which is believed to play an equivalent part in supersonic flutter to the Theodorsen function in the flutter problems of incompressible flow. The results are presented in Technical Note 2333.

Investigation of Wings and Bodies at Transonic and Supersonic Speeds

An essential part of the correlation of aerodynamic data is a knowledge of the correspondence between the flow fields about similar bodies at related speed conditions. An investigation was made, therefore, at the Ames Laboratory which extended similarity laws for transonic flow to include finite-span wings. Under the assumptions of transonic small-perturbation potential theory, it was shown that similitude in pressure, lift, pitching moment, and pressure-drag coefficients depend upon the constancy of two parameters. The application of these results led to an essential improvement in the manner of relating experimental wing characteristics at near-sonic speeds. This work has been reported in Technical Note 2273.

Source distribution methods for evaluating the aerodynamics of thin finite wings at supersonic speeds are summarized and extended in Report 951. The fundamental equations were derived in general form for both time-independent and time-dependent wing motions and were applied to solve a large variety of aerodynamic problems. In Technical Note 2303 a method was developed for relating the solution of a wing to the known solution of a simpler wing. This method permits complicated flow fields to be solved in a straightforward manner.

At the Johns Hopkins University, von Karman's Fourier integral method in supersonic wing theory, derived directly from the basic concepts of the harmonic source and doublet, has been applied to investigate the general solution of the wave drag of a tapered swept wing with a symmetrical diamond airfoil profile, covering various geometrical arrangements of the planform. The theory has also been applied to find the downwash distribution in the plane of the wing on which the pressure distribution is preassigned. A number of examples are given. This work has been done under contract to the NACA and the results are presented in Technical Note 2317.

The flow around cones without axial symmetry and moving at supersonic velocity has been analyzed and the results of this analysis are presented in Technical Note 2236. Singular points were shown to exist in the flow around the cone if no axial symmetry exists. The concept of a vortical layer around the cone at small angles of attack was introduced, and the correct values of the first-order terms of the velocity components were determined. It was shown that good agreement with experimental results can be obtained if the complete equation for the pressure distribution is used.

The transonic similarity law, as applied to bodies of revolution, has been investigated and the results presented in Technical Note 2239. The results obtained were in approximate agreement with those of von Karman in the region of the flow field not too close to the body. In the neighborhood of the body a different similarity law was obtained. In another investigation the integral method used to obtain compressible flow past two-dimensional shapes (Technical Note 2130) was applied to the calculation of the compressible flow past slender bodies of revolution. Good agreement of the resulting velocities on ellipsoids of revolution with those obtained by other methods was found. The investigation is reported in Technical Note 2245.

The pressure acting on the base of a body of revolution flying at supersonic velocity is of considerable importance because the base drag can, in some cases, represent more than half of the total drag. It is essential that the factors contributing to this drag be explored to enable a reasonable drag prediction to be made in the design of missiles and to provide information from which possible base-drag reductions may be realized. One such factor is the presence of tail surfaces near the base of the body. Since the pressures in the vicinity of the trailing edge of the tail surfaces at zero angle of attack are normally less than the free-stream values, the interaction of these pressures with the flow behind the base may produce a reduction in the base pressure and, hence, an increase in the base drag. Accordingly, experimental measurements of the base pressure on an unboattailed body of revolution in combination with rectangular tail surfaces were made at the Ames Laboratory to investigate the effects of tail surfaces on base drag. The results of the investigation showed that the addition of tail surfaces with the trailing edge near the base of the body incurred a significant increase in base drag. For example, the increase was about 70 percent at a Mach number of 1.5 for a cruciform tail having a 10-percent-thick biconvex airfoil section. The base-drag penalty due to tail surfaces was found to increase with an increase in the airfoil thickness ratio and with the number of tail surfaces and to decrease with an increase in Mach number. It was also found that this base-drag increment could be essentially eliminated by moving the tail so that the trailing edge was about one chord-length ahead of or behind the base of the body. The results are presented in Technical Note 2360.

Research in the Hypersonic Speed Range

In the Thirty-sixth Annual Report several facilities and techniques permitting supersonic research to be extended into the hypersonic speed range were described. During the past year this work has been continued and, in addition, progress has been made in extending theoretical calculations into the hypersonic range.

The accuracy of Tsien's hypersonic similarity rule, and the range of Mach numbers and fineness ratios over which it can be applied, have been investigated theoretically. A first investigation, which ignored rotation effects, showed that the rule applied with good accuracy over a range from moderate supersonic speeds up to hypersonic speeds for a wide range of body fineness ratios. This work has been reported in Technical Note 2250. An investigation of the effects of rotation, presented in Technical Note 2399, showed that the omission of these effects in the previous investigation did not have a significant effect on accuracy within the expected range of validity of hypersonic similarity.

An analysis has been performed to determine the lift and drag characteristics of conical bodies, flat plates, cylinders and spheres in a free-molecule flow field. The calculations were made for a range of Mach numbers from 0 to 24. It was found that the aerodynamic coefficients approached constant values at the very high speeds. It was also found that the lift-drag ratio for bodies in a free-molecule flow field are extremely low. The results are reported in Technical Note 2423.

Theoretical investigations have also been made to determine the similarity law for hypersonic flow about slender three-dimensional shapes in terms of customary aerodynamic parameters. A first investigation, which considered only steady flows, employed the law to determine relation for correlating the pressures acting on, and the aerodynamic coefficients of, related bodies and results are reported in Technical Note 2443. In the special case of inclined bodies of revolution, the expressions for the aerodynamic coefficients were extended to include some significant effects of the viscous cross force.

A theoretical analysis which determines the airfoil profile having minimum pressure drag for a given structural requirement was reported in Technical Note 2264. The general method was developed and applied to linearized flow theory. The principal results of the investigation were that the optimum airfoil at hypersonic velocities has a trailing-edge thickness slightly less than the maximum airfoil thickness and the optimum airfoil at supersonic velocities generally has a moderately thick trailing edge. Curves were developed which enable optimum airfoil profiles to be determined rapidly for a given Mach number, base pressure, and structural requirement.

Condensation of the components of air has been found to occur in hypersonic wind tunnels. Because of the rapid expansion and cooling of the air in the nozzles of these tunnels, the temperature of the air drops below the liquefaction point. In order to study this condensation process, the Langley Laboratory has made an investigation of optical methods for measuring size and concentration of condensation particles, and it has been found that the polarization and angular distribution of light scattered by condensation particles can be used to measure these quantities. The results of this investigation are presented in Technical Note 2441.

Boundary-Layer Research

The existence of localized regions of laminar-boundary-layer separation on airfoils both behind the position of minimum pressure at the ideal angle of attack and near the leading edge at high angles of attack has been recognized, but the parameters controlling such regions have not been fully understood. Consequently, an experimental investigation was made at the Langley Laboratory to study the localized region of laminar separation behind the point of minimum pressure on an NACA 66_3–018 airfoil section at zero angle of attack and at several Reynolds numbers. The results, presented in Technical Note 2338, confirmed the idea that such separation regions are characterized by a length of laminar boundary layer followed by transition and subsequent reattachment as a turbulent boundary layer and established some of the quantitative characteristics of the phenomenon.

At the Lewis Laboratory an analysis has been made of the stability of the laminar boundary layer between parallel streams of an incompressible fluid. Calculations based on this analysis showed that the flow instability occurs at much lower Reynolds number for the free boundary layer between streams than for the boundary layer on a flat plate with no pressure gradient. The results of this study are presented in Report 979.

An investigation of methods for treating the three-dimensional compressible laminar boundary layer is reported in Technical Note 2279. The equations of motion are shown therein to be simplified by the introduction of a two-component vector potential and by the use of a transformation which converts the equations into nearly incompressible form. Several examples, including the flow over flat plates with arbitrary leading-edge contours, are discussed.

Numerical solutions of quantities appearing in the von Karman momentum equation for the development of a turbulent boundary layer in plane and in radial compressible flows along thermally insulated surfaces are presented in Technical Note 2337 for a range of Mach number from 0.1 to 10. Through the use of these tables, approximate calculation of boundary-layer growth is reduced to routine arithmetic computation.

Experimental data, from several sources, for skin friction of turbulent boundary layers under adverse pressure gradients are analyzed in Technical Note 2431. Data obtained by momentum-balance methods were compared with data obtained by hot-wire and heat-transfer methods. A new integral energy parameter was introduced and its relation to skin-friction data was demonstrated on the basis of available material.

At the Ames Laboratory an analysis has been made to determine the skin-friction and heat-transfer characteristics of the turbulent boundary layer on a flat plate at supersonic speeds. A review of existing analyses has also been made and a test performed in the Ames heat transfer tunnel to measure the skin friction in the turbulent boundary layer of a flat plate at a Mach number of 2.4. It was found that the analysis which most closely corresponded to the experimental results was an extended version of the Frankl-Voishel analysis, which has been reported in Technical Memorandum 1053. The test data and analysis have been reported in Technical Note 2305.

A series of heat-transfer investigations were conducted on bodies of revolution with laminar boundary layers at Mach numbers from 1.49 to 2.13. In addition, a comparison between theory and experiment has been made for a body of revolution with a laminar boundary layer and a nonuniform surface temperature. The theoretical and experimental heat-transfer results are in good agreement for both heated and cooled bodies with both uniform and nonuniform surface temperatures. The qualitative effects of heat transfer on transition were found to be in agreement with the implications of Lees' boundary-layer-stability theory.

Detailed measurements of shock-wave boundary-layer interaction which have been made in wind tunnels have been limited to small or moderate Reynolds numbers, and previous flight tests at high Reynolds numbers have been limited to pressure measurements. Therefore, tests were made on an airplane wing in flight to investigate the region of shock-wave interaction with a thick turbulent boundary layer at full-scale flight Reynolds numbers, utilizing both a schlieren apparatus and pressure measurements. Good correlation with theoretical and wind-tunnel investigations of boundary-layer shock-wave interaction was obtained, particularly with respect to the lower Mach numbers at which a forked or bifurcated type of shock wave appeared. The boundary layer did not appear to thicken behind the normal shock wave. Considerable thickening, associated with separation, did occur, however, with increasing Mach number after the formation of the forked shock wave. The density gradient in the boundary layer appeared to increase markedly just behind the shock wave. This stronger gradient, however, appeared to be dissipating at approximately five to six boundary-layer thicknesses behind the shock.

At the Lewis Laboratory supersonic flow against blunt bodies placed in boundary layers or wakes has been investigated and is discussed in Technical Note 2418. It was concluded that wedge-shaped or conical dead-air regions should form ahead of the body if part of the upstream velocity profile is subsonic and if the body is fairly thick relative to the initial boundary layer or wake thickness. A quantitative theoretical analysis of this type of flow was made and the results were compared with experiment.

In a contract investigation carried out at the California Institute of Technology, measurements have been made at Mach numbers from about 1.3 to 1.5 of reflection characteristics and the relative upstream influence of shock waves impinging on a flat surface with both laminar and turbulent boundary layers. The difference between impulse and step waves is discussed and their interaction with the boundary layer were compared in Technical Note 2334. General considerations on the experimental production of shock waves from wedges and cones and examples of reflection of shock waves from these bodies were presented, as were also some examples of reflection of shock waves from supersonic shear layers.

At the National Bureau of Standards an investigation sponsored by the NACA was conducted on a turbulent boundary layer near a smooth surface with pressure gradients sufficient to cause flow separation. The Reynolds number was high, but speeds were entirely within the incompressible flow range. The investigation consisted of measurements of mean flow, three components of turbulence intensity, turbulent shearing stress, and correlations between two fluctuation components at a point between the same component at different points. Results are given in Technical Note 2133 in the form of tables and graphs. The discussion deals first with separation and then with the more fundamental question of basic concepts of turbulent flow.

Aerodynamic Heating and Heat Transfer

As was pointed out in the Thirty-sixth Annual Report, knowledge of aerodynamic heating and heat transfer phenomena has become of increasing importance as airplane and missile flight speeds have increased into the supersonic region, and during the past year considerable effort has been directed toward the understanding of these phenomena.

Tests have been conducted at the Ames Laboratory to determine the effect of surface heating on the transition Reynolds numbers on a flat plate at a Mach number of 2.4 It was found that surface heating had a strong effect in lowering the minimum Reynolds number for transition. Measured skin-friction coefficients for the laminar portion of the boundary layer were in excellent agreement with other investigations and were 35 percent higher than the values predicted theoretically by Crocco. The data have been reported in Technical Note 2351.

Most aircraft or missiles will not have a constant surface temperature. Consequently, it is necessary to determine the effect of a variable surface temperature on the local heat-transfer rate in order to design skin-cooling systems. An analysis has been made which shows the effect of a variable stream-wise surface temperature on local heat-transfer rates. An interesting side light arising from the investigation shows that the use of plug-type heat meters, in which a small segment of the aircraft skin is heated or cooled to a different temperature than the surrounding skin, may introduce large errors in the determination of the local heat-transfer coefficients. This analysis has been published as Technical Note 2345.

An analytical method is presented in Technical Note 2296 for obtaining turbulent temperature recovery factors for a thermally insulated surface in supersonic flow. The analysis, conducted at the Lewis Laboratory, indicated that the recovery factor decreased with increasing Mach number. For the range of Prandtl number considered (0.65 to 0.75), the recovery factors at a stream Mach number of 10 were, on the average, about 5 percent lower than the limiting values at zero Mach number.

A comparison has been made of free-molecule-flow theory with experimental measurements of drag and temperature-rise characteristics of a transverse circular cylinder. The measured values of the cylinder center-point temperature confirmed the salient point of the heat-transfer analysis, which was the prediction that an insulated cylinder would attain a temperature higher than the stagnation temperature of the stream. Good agreement was obtained between the theoretical and experimental values for the drag coefficient. The data have been reported in Technical Note 2244.

Experiments have been made at the Ames Laboratory to determine the heat-transfer characteristics of cylinders over a wide range of densities encompassing the free-molecule, slip and continuum flow regimes, and the results are presented in Technical Note 2438. Good correlation of the data was obtained over a range of Reynolds numbers from 0.02 to 100 and a range of Mach numbers from 1.9 to 3.2. The Knudsen number (ratio of mean free molecular path to cylinder diameter) varied from 0.02 to 10. Several important conclusions were drawn from the results of this investigation: It was found that fully developed free-molecule flow occurred when the Knudsen number was 2 or greater. For Knudsen numbers greater than 0.2, the temperature recovery factor exceeded unity even though free-molecular flow was not fully developed.

In an investigation at the Lewis Laboratory, analyses were made for fully developed laminar and turbulent flow in smooth circular tubes of fluids having a Prandtl number of 1.0. The analyses took into consideration the variation of fluid properties. Velocity and temperature profiles, together with local heat-transfer and friction coefficients, were predicted. In order to check the analysis for turbulent flow, velocity and temperature profiles and corresponding local heat-transfer and friction coefficients were also experimentally determined for air in smooth tubes at high heat-transfer rates. The analytical and experimental results were found to be in good agreement. Both indicated that for the turbulent flow of gases the radial velocity and temperature profiles tended to become more uniform as the surface-to-fluid temperature ratio increased. At constant Reynolds number, the local heat-transfer and friction coefficients decreased with an increase in surface-to-fluid temperature ratio. The effects of temperature ratio could be eliminated when the fluid properties, including density in the Reynolds number, were evaluated at a temperature close to the average of the fluid and surface temperatures. The results of these analyses are presented in Technical Notes 2242 and 2410.

Average heat-transfer and friction coefficients have also been measured for the turbulent flow of air in smooth tubes. This investigation covered an over-all range of Reynolds numbers up to 500,000, tube exit Mach numbers up to 1.0, inlet-air temperatures from 535° to 3050° R., average surface temperatures from 535° to 1500° R., length-diameter ratios from 30 to 120, and heat fluxes to 150,000 BTU per hour per square foot. Three tube entrance configurations were studied. Most of the data are for heat addition to the air; some results are for heat extraction from the air. Data have also been obtained for tubes of noncircular cross section. An effect of surface-to-fluid temperature ratio was found to exist when the average coefficients were correlated with other pertinent variables by conventional methods. The effect was eliminated in the same manner as for the local coefficients. Correlation equations for heat transfer and friction were obtained which adequately represent all the experimental data for smooth tubes.

An analytical investigation of the compressible flow processes occurring in the passages of high heat-flux exchangers is continuing at the Lewis Laboratory. Charts are presented in Technical Notes 2186 and 2328 for convenient determination of the compressible-flow pressure drop sustained by monatomic and diatomic gases (assuming constant heat capacities during the process) flowing at high subsonic speeds in constant-area passages under the simultaneous influence of friction and heat addition.

STABILITY AND CONTROL

Static Stability Investigations

The use of end plates has been suggested as a possible means of relieving some of the adverse lateral stability and control problems experienced with swept wings. An investigation was therefore conducted in the Langley 300-mph 7- by 10-foot tunnel to determine the effects of end plates of various sizes and shapes on the stability and control characteristics of several swept wings. The results of this investigation, presented in Technical Note 2229, indicate that at low lift coefficients the addition of end plates increased the slope of the lift curve, reduced maximum lift-drag ratio, generally decreased maximum lift coefficient, and increased longitudinal stability. It was also found that the variation of effective dihedral with lift coefficient for the wing-end plate combinations investigated was reduced by an increase in the size of the end plate.

A knowledge of the character of the downwash fields behind wings is required for the rational design of horizontal tail surfaces as well as for the analysis of the longitudinal stability characteristics of an airplane. One theoretical study of this problem has resulted in the development of a method for calculating the downwash field behind lifting surfaces at subsonic and supersonic speeds. A description of the method, together with an illustrative example of its use, is contained in Technical Note 2344. In connection with another study, a series of charts and tables was prepared from which the downwash behind horsehoe vortices in incompressible flow can be obtained. The use of these charts and tables in connection with the calculation of the downwash behind wings of arbitrary planform is described in Technical Note 2353, which also contains illustrative examples. Report 983 describes the use of line vortex theory for the calculation of supersonic downwash and Technical Note 2141 contains charts for the estimation of downwash behind rectangular, trapezoidal, and triangular wings which were prepared on the basis of line vortex theory.

Studies of Dynamic Stability

At the Ames Laboratory the dynamic lateral stability characteristics of a dive-bomber type of airplane were investigated in flight to determine the cause of a small amplitude continuous motion referred to as "snaking." The results of this investigation, reported in Technical Note 2195, indicate that the floating characteristics of the rudder were affected by Mach number and had an appreciable effect on the snaking of the airplane. Rudder modifications resulting in an increase in the restoring tendency of the rudder proved successful in eliminating this undesirable lateral oscillation.

The effects of control centering springs on the apparent spiral stability characteristics of a typical high-wing personal-owner airplane have been investigated in flight. Control centering was provided for both the ailerons and rudder by means of preloaded springs. Results of the investigation, reported in Technical Note 2413, show that the airplane appeared to be spirally unstable with controls free when the centering springs were disengaged because of moments resulting from out-of-trim control position. With centering springs engaged, however, the airplane quickly returned to straight and level flight with the controls freed following an abrupt disturbance. The report also includes information concerning the flying qualities of the airplane in rough air.

At the Langley Laboratory free-flight-tunnel studies were made to determine the effects of mass distribution on the low-speed dynamic lateral stability and control characteristics of a free-flying model. In this investigation the longitudinal and lateral mass distributions of the model were varied, both independently and simultaneously, while the relative density factor was held constant. The results of the investigation, presented in Technical Note 2313, show that increases in the rolling and yawing moments of inertia reduced the controllability of the model by increasing the time required to reach a given angle of bank and caused the flying qualities to become less desirable. The study also showed that, as moment-of-inertia increased, the oscillatory stability generally decreased and flight behavior became progressively less satisfactory.

A study has been made of methods for the evaluation of dynamic stability parameters from flight-test data. The ability to evaluate these parameters by this technique will make it possible to obtain information on the variation of these factors in the critical transonic range. The results of this study are reported in Technical Note 2340 and mathematical aids for the analysis presented in this paper are reported in Technical Note 2341.

A summary of available methods for estimating subsonic dynamic lateral stability and airplane response characteristics and for estimating the aerodynamic stability derivatives required in these calculations has been made. The results of this summary are presented in Technical Note 2409. This paper presents methods for obtaining time histories of lateral motions, period and damping characteristics, and the lateral stability boundaries, and also provides references to related experimental data. A brief discussion of the evaluation of transonic and supersonic stability parameters is included.

A matrix method has been derived to determine the longitudinal stability coefficients and frequency response characteristics of aircraft from arbitrary maneuvers. This method is presented in Technical Note 2370 and can be applied to time history measurements of such quantities as angle of attack, pitching velocity, load factor, elevator angle, and hinge moment to obtain over-all coefficients. With simple additional computations, it can also be used to determine frequency response characteristics and may be applied to other problems expressed by linear differential equations.

A theoretical investigation was made using LaPlace transformations to determine the effect of nonlinear stability derivatives on airplane lateral stability characteristics, with particular emphasis placed on snaking. The nonlinearities assumed corresponded to the condition where values of the directional stability and damping-in-yaw derivatives are zero for small angles of sideslip. Results of this study are presented in Technical Note 2233 and indicate that under certain conditions the assumed nonlinearities caused a motion which had different rates of damping for large and small amplitudes and little damping at the small amplitudes.

Another theoretical study was made to determine the effects of fuel motion on airplane dynamics. Results of this study are presented in Technical Note 2280. In this report, the general equations of motion for an airplane with spherical fuel tanks are presented. The motion of the fuel is approximated by the motion of solid pendulums. The analysis applies to fuel tanks of any shape if the fuel motion can be represented in terms of undamped harmonic oscillators. The study shows that fuel motion may have an appreciable effect on the dynamic behavior of an airplane.

Analytical and experimental investigations have been made to determine the effects of wing interference on vertical tail effectiveness at low speeds. These studies have been reported in Technical Notes 2332 and 2175. Comparisons of the estimated and experimental results indicate that the inclusion of a factor to account for wing interference effects provides agreement between the experimental and estimated values of the tail contribution to the rolling derivatives.

The lift and pitching moment produced by angle of attack, steady state pitching, and constant vertical acceleration for a series of thin sweptback streamwise-tip wings of arbitrary sweep and taper have been determined through the use of linearized supersonic flow theory. The method of analysis and the results from the angle of attack and steady state pitching studies are presented in Technical Note 2294 for a range of supersonic Mach numbers that allow the wing leading edge to be subsonic and the trailing edge to be either supersonic or subsonic. The method of analysis and studies of the lift and pitching moment due to constant vertical acceleration are reported in Technical Note 2315 for a range of supersonic Mach numbers for which the wing leading edge is subsonic and the trailing edge supersonic. Design charts are presented in both of these reports that permit rapid estimates of wing lift and pitching moment for given values of aspect ratio, taper ratio, Mach number, and leading-edge sweep.

Automatic Stability Studies

The application of automatic controls to the operation of aircraft complicates the analysis of aircraft dynamics. In order to gain a more thorough knowledge of the factors involved in the automatic control and stabilization of airplanes and missiles, research has been intensified on means of solving current and anticipated problems in this field.

A survey has been made of various techniques used in analysis of the stability and performance of automatically controlled aircraft. This survey deals with methods commonly applied to the linear, continuous control type of system ordinarily used in aircraft, and has been published as Technical Note 2275.

An investigation was carried out to evaluate the suitability of proposed methods for analyzing servomechanism systems incorporating feedback. This study is described in Technical Note 2373 and deals with an extension of frequency response techniques for the analysis of an autopilot-aircraft combination. This paper contains comparisons between experimental data and results obtained by the use of the practical methods of calculation which were developed.

An experimental investigation was conducted to determine the response characteristics of four airplane configurations employing an autopilot sensitive to yawing acceleration. The results of this study are pre sented in Technical Note 2395 and show that predictions based on the assumed autopilot characteristics did not agree with experimental data because the assumptions did not satisfactorily approximate the frequency response characteristics of the autopilot.

A theoretical method was derived for determining the control gearings and time lags necessary for a specified damping of the lateral motions of an aircraft equipped with an autopilot. The method was applied to a typical airplane equipped with an autopilot which deflects the rudder in proportion to yawing angular acceleration. The results of this study, presented in Technical Note 2307, indicate that the types of motion predicted for this airplane-autopilot system by the derived method are in good agreement with those obtained by a step-by-step method.

Research on Controls

Theoretical and experimental research on the effects of numerous control design variables on the characteristics of controls has been continued during the past year.

In one theoretical study, an analysis was made of the effects of sweep, aspect ratio, taper ratio, and Mach number on the characteristics of inboard trailing-edge flaps at supersonic speeds. This study considers cases where the Mach lines lie behind the leading and trailing edges of the flap. Design charts developed from the analysis and presented in Technical Note 2205 enable a rapid estimation to be made of the characteristics due to deflection for control surfaces for which the Mach lines from the flap tips do not intersect on the control surface.

In another theoretical analysis, supersonic control characteristics were determined through the use of existing conical-flow theory. This analysis applies to a broad range of trailing-edge control configurations having supersonic edges and covers such variables as wing aspect ratio, taper ratio, sweep and control location. The results of this study, presented in Technical Note 2221, are in the form of equations and charts from which lift, pitching-moment, rolling-moment, and hinge-moment coefficients may be determined.

The stability and control characteristics of wings of trapezoidal planform were investigated by means of linearized supersonic theory to determine the characteristics of various wing-flap combinations. Expressions for the stability characteristics were derived by treating the configuration as a complete wing, and the control characteristics were determined by treating it as a rectangular wing with half-delta tip flaps. The results, reported in Technical Note 2336, were compared with corresponding results for several other wing-flap combinations and it was found that, of the wings considered, a triangular wing with either half-delta tip flaps or trailing-edge controls exhibited the most favorable characteristics.

As part of the general NACA program to investigate the applicability of various types of lateral control devices to wings suitable for high-speed flight, an experimental investigation was conducted in the Langley 300-mph 7- by 10-foot tunnel to determine the effect of aspect ratio on the lateral control characteristics of a series of untapered, unswept, low-aspect-ratio wings equipped with continuous type retractable spoiler ailerons. One swept wing was included in the study for purposes of comparison, and, in addition to being equipped with the continuous type spoiler, was also investigated when equipped with a stepped or segmented spoiler aileron. The results of the study, reported in Technical Note 2347, indicate that for the unswept wings continuous spoiler ailerons became progressively more effective in producing roll as wing aspect ratio was increased. The continuous spoiler aileron was less effective on the swept wing than on a straight wing of comparable aspect ratio. On the swept wing it was found that the effectiveness of the continuous spoiler generally increased as the spoiler was moved progressively inboard, while the opposite was true for the stepped spoiler.

An experimental investigation was conducted in the Langley 300-mph 7- by 10-foot tunnel to determine the lateral control characteristics of an untapered semispan wing having either 0° or 45° of sweep and equipped with a plain unsealed aileron. The span and spanwise location of the aileron were varied in order to determine the optimum configuration for rolling effectiveness. The results of this investigation, reported in Technical Notes 2199 and 2316, indicate that for either the swept or unswept wing, a given partial span aileron was most effective in producing roll and in maintaining effectiveness over a large angle of attack range when located on the outboard portion of the wing. It was also found that, although the rate of change of aileron hinge-moment coefficient with angle of attack could not always be satisfactorily predicted for the swept wing, existing empirical methods for predicting the rate of change of rolling moment coefficient and aileron hinge-moment coefficient with aileron deflection provided satisfactory agreement with the experimental results for both the straight and swept wings.

In order to determine the effect of aspect ratio on the low-speed lateral control characteristics of low-aspect-ratio wings, a series of four unswept, untapered wings with aspect ratios from 1 to 6 was investigated in the Langley 300-mph 7- by 10-foot tunnel. The wings were equipped with plain sealed ailerons of various spans located at several spanwise stations. The results of this study are presented in Technical Note 2348 and show that the variation of aileron effectiveness with aspect ratio could not be accurately predicted for all ailreon spans by any of the theoretical methods utilized in this investigation.

Studies of Damping Derivatives

Theoretical and experimental studies have been extended in the past year to develop methods for the reliable evaluation of damping derivatives in all speed ranges.

One theoretical method, described in Technical Note 2197, was developed for calculating the pressure distribution and damping in pitch at supersonic Mach numbers for thin swept wings having subsonic edges. The method consists of the calculation of a basic pressure distribution and the correction of this distribution to account for the effects of the subsonic trailing edges and tips. These data are then used to determine the damping-in-pitch characteristics.

Technical Note 2285 presents an evaluation of the supersonic damping in roll of cruciform delta wings by means of linearized theory. Both subsonic and supersonic leading edges were considered. The effect of increasing the number of wing panels from four to an arbitrary number under the restriction of low-aspect ratio was determined, and the damping for an infinite number of wing panels was evaluated without restriction as to aspect ratio or Mach number. A similar theoretical study is reported in Technical Note 2270 in which the theory of slender wings was used to determine the characteristics in roll of slender cruciform wings. This analysis shows that, for the cruciform wing, the damping-in-roll is considerably greater than that of a plane wing having the same aspect ratio and that the rolling effectiveness is less than that of a plane wing.

Experimental studies of damping derivatives have been carried out in the rolling and curved flow facilities of the Langley stability tunnel. One investigation was conducted to determine the effects of horizontal tail location on the low-speed static longitudinal stability and damping in pitch of a model with 45° swept wings and tail. The results, published in Technical Note 2381, indicate that at high angles of attack, lowering the horizontal tail increased the static longitudinal stability and decreased the damping in pitch. A related investigation is reported in Technical Note 2382. In this study, horizontal tail size and tail length are variables. The study shows that the contribution of the horizontal tail to static longitudinal stability was directly related to tail size and length, while damping in pitch was related to tail size and the square of the tail length.

Another investigation was conducted in the Langley stability tunnel to determine the effect of vertical tail area and tail length on the yawing stability of a model with a swept wing. Technical Note 2358 contains the results of this study, which indicate that the effects of wing-fuselage interference for the midwing configuration studied were small over most of the angle-of-attack range. Large interference effects on the vertical tail effectiveness were apparently produced by both the wing and fuselage at moderate and high angles of attack, but because these effects tended to cancel each other, the gross effects were small.

Investigation of Flying Qualities

The increasing operational speeds of current and proposed aircraft have aggravated the problems involved in defining and achieving flying qualities compatible with safety, performance, and piloting requirements. Research to isolate the effects of numerous design parameters on flying qualities has continued to receive attention.

Two design factors which can significantly affect the flying qualities of an airplane are the wing airfoil section and the type of lateral-control device employed. To determine the effects of one of these design variables on the flying qualities of an airplane model, an investigation was conducted in the Langley free-flight tunnel to determine the effects of round and sharp leading-edge airfoil sections on the dynamic lateral stability and control characteristics. Two models were used in the study, one representative of a current fighter airplane with respect to inertia characteristics and the other representative of a possible future design in which mass is concentrated along the fuselage. The results of the investigation, reported in Technical Note 2219, indicate that airfoil section has no apparent effect on the flying qualities of the model with high fuselage inertia. The normal inertia model when equipped with the wing having a round-nose airfoil section exhibited adverse yawing during aileron rolls which increased with decreases in directional stability. This same model, however, exhibited no adverse yawing when fitted with the wing having a sharp-nose airfoil, even at low values of directional stability. This difference in flying characterstics is attributed to the adverse yawing moment due to rolling of the round-nose wing, which on the other model is apparently masked by the high fuselage inertia.

Another investigation was conducted in the Langley free-flight tunnel to compare the dynamic lateral-control characteristics of stepped plug ailerons with those of conventional plain flap ailerons. The model employed in this study had a low-aspect-ratio swept wing equipped with full span flaps. The results of the investigation, published in Technical Note 2247, show that when the lateral stability characteristics were satisfactory the controllability of the model was better with plug ailerons alone than with conventional ailerons alone because the loss of rolling effectiveness due to the adverse yaw associated with the flap aileron was more objectionable than the lag associated with the plug ailerons. For conditions of low dynamic lateral stability, the conventional ailerons alone provided better controllability than either plug ailerons alone or a combination of flap ailerons and rudder. Although the time lag of the plug ailerons was excessive according to existing flying qualities requirements, the pilot considered the controllability of the model to be satisfactory.

The improvement of passenger comfort in airplanes, through a reduction of accelerations caused by rough air, has become of greater interest as airplane operational speeds have increased. One method which has been suggested for providing increased comfort in high-speed airplanes is to have the wing flaps operated by an angle-of-attack or acceleration-sensing device in such a manner as to reduce accelerations due to gusts. A theoretical study of such a system has been made and is reported in Technical Note 2416. The results of the study show that flaps with characteristics similar to those of conventional landing flaps are unsuitable for acceleration alleviation because of airplane pitching motions resulting from flap deflection. The analysis indicates that the flaps should produce zero pitching moment about the wing aerodynamic center and downwash at the tail in the opposite direction from that normally expected in order to be satisfactory for this application. Various means of achieving these characteristics are suggested, and it is shown that flaps possessing these desirable characteristics would be effective in reducing accelerations in rough air when combined with an angle-of-attack or acceleration-sensing device.

In the previous study no attempt was made to consider the practical problems involved in the design of a mechanism for acceleration alleviation. To help evaluate one of these problems, an experimental investigation was made to determine the ability of a vane mounted ahead of the nose of an airplane to give an indication of the average angle of attack over the entire wing span during flight through rough air. The results of this investigation are presented in Technical Note 2415 and show that the device gives a sufficiently accurate indication of average angle of attack over the wing span to allow its use in an acceleration alleviation system.

Spinning Investigations

The spin and recovery characteristics of airplanes are dependent on many aerodynamic and structural design parameters. In order to provide the designer with information on which of these parameters may be of primary importance to the recovery characteristics of any particular aircraft configuration, research on the problems of spinning has continued in the Langley 20-foot free-spinning tunnel.

One investigation was conducted to determine the effects of mass and dimensional variations on the spin and recovery characteristics of a model representative of current four-place light airplanes. The results, which are reported in Technical Note 2352, indicate that satisfactory recovery characteristics could be obtained for all of the mass distributions studied provided that the proper sequence of control movements for recovery was followed. It was also found that unless the rudder can be made to float against the spin, recovery by releasing controls may be difficult to achieve unless the elevator floats below neutral. Other requirements for spin recovery set forth in current regulations could probably be met for the model arrangements investigated by restricting center-of-gravity location and providing a high value of tail damping.

Because a previous study had indicated that a horn-balanced rudder might possess the desirable characteristic of floating against the spin, an experimental investigation was undertaken to determine the floating characteristics of full-length plain and horn-balanced rudders during rotary tests at spinning attitudes of a model of a typical low-wing light airplane. The effects of the horizontal tail and wing on the rudder floating characteristics were also determined. The results of this investigation, reported in Technical Note 2359, indicate that for this configuration the rudder was in the wake of the stalled wing and oscillated violently for high spinning angles of attack. At lower angles of attack, or for the case in which the tail was outside the wake of the stalled wing, the horn-balanced rudder had more desirable floating characteristics than a plain rudder, although neither would fulfill the floating deflection requirements for control-free spin recovery.

AIRCRAFT PROPELLERS

In the field of propeller vibration, Technical Note 2308 has been published in continuation of the investigation of first-order propeller vibration on a twin-engine, straight-wing airplane in the Ames 40- by 80-foot tunnel. A procedure has been developed for computing the flow field at the propeller plane to a sufficient degree of accuracy to permit satisfactory calculation of the propeller vibratory stresses. In the procedure, account is taken of the upwash contributions of the wing, fuselage, and nacelles and their mutual interference effects. The analysis shows that the nacelle caused an unexpectedly large effect which, if ignored, could readily cause disagreement between the magnitude of computed and measured vibratory stresses.

In another propeller vibration investigation, the existing analysis applicable to the prediction of first-order exciting forces for the straight-wing propeller case has been extended to include the swept-wing propeller combination. With the aid of the straight-wing analysis, a typical swept-wing propeller-driven airplane design has been studied to examine the magnitude of the once per revolution exciting forces which could exist. It has been found that in addition to the usual exciting forces, a new and relatively important one is added where a swept wing is used; this results from the relative fore and aft movement of the propeller blade with respect to the leading edge of the wing which is swept with respect to the propeller plane of rotation. It was found further that the effects of Mach number are such as to reduce the magnitude of the once-per-revolution exciting forces.

SEAPLANES

Hydrodynamic studies have continued in the Langley tanks to provide basic and design data for the development of water-based airplanes.

One study reported in Technical Note 2297 investigated the use of high angles of dead rise on high-length-beam-ratio flying-boat hulls as a means for reducing water loads encountered during rough-water operation. An increase in angle of dead rise from 20° to 40° increased the take-off stability and substantially improved the spray characteristics of a high-length-beam ratio hull. An expected decrease in take-off performance was evidenced by increases in take-off time and distance of 25 and 30 percent, respectively. The over-all rough-water landing behavior was improved; the maximum vertical and angular accelerations were reduced approximately 55 and 30 percent, respectively. The reduction in vertical acceleration was in good agreement with that predicted by impact theory.

ROTARY WING AIRCRAFT

Based on the results of flight investigations of several single-rotor helicopters, preliminary qualitative requirements for satisfactory flying and handling qualities of helicopters have been established. Progress in designing helicopters to meet these requirements, however, has been handicapped by the need for a method permitting sufficiently accurate prediction of the flying qualities of a helicopter at the design stage. To help fill this need, existing rotor theory, accurate for the calculation of rotor performance and blade motion, has been extended (Technical Note 2309) to permit the prediction of those rotor characteristics that influence the flying qualities. Variation of the longitudinal derivatives of rotor resultant force, rotor pitching moment, and rotor torque with operating parameters such as rotor angle of attack, collective pitch, forward speed, and rotational speed may be determined. The usual simplifying assumption that the rotor resultant force vector is perpendicular to the rotor tip path plane is shown by the results of this theory to lead in many cases to grossly incorrect longitudinal stability derivatives. The theory also indicates that the increase in rotor load factor with an incremental increase in angle of attack is approximately linear with increasing forward speed. This is in contrast to the airplane where the increase is as the square of the forward velocity.

Increases in the forward speed of helicopters are expected to require increases in rotor tip speeds in order to avoid excessive tip stalling on the retreating blade. At tip speeds within the transonic range the rotor will suffer some performance loss due to compressibility. In order to gain an insight into the magnitude of this compressibility-induced performance loss and to furnish a check on theoretical methods of estimating the loss, two conventional full-scale rotors, one having linear twist and the other untwisted, have been tested to tip speeds up to 770 feet per second on the Langley helicopter test tower. The results of this study, reported in Technical Note 2277, show that both rotors suffered increasing compressibility losses as the tip speed increased to the maximum speed studied. Linear twist delayed the onset of compressibility losses. For the blades investigated good agreement was obtained between the measured and predicted drag-divergence Mach number.

As part of a general investigation of the aerodynamic characteristics of various multirotor configurations, an investigation to determine the static-thrust performance of two full-scale coaxial helicopter rotors has been conducted in the Langley full-scale tunnel. One coaxial rotor was equipped with blades tapered in both planform and thickness and the other with blades tapered in thickness only. The results, presented in Technical Note 2318, show the hovering performance of each rotor in the coaxial configuration and with the upper rotor removed. The effect of application of yaw control on the hovering performance of the coaxial configurations is also presented. A comparison of measured and predicted hovering performance is included.

As a part of the investigation of multirotor configurations a study was made of the air-flow patterns through small scale single, coaxial, and tandem rotor models. The balsa-dust technique of air-flow visualization was employed. The photographic results, presented in Technical Note 2220, provide a qualitative interpretation of the transient and steady-state flow through the rotors.

A theoretical study of the rigid-body oscillations in hovering of helicopter rotor blades has been made by the Polytechnic Institute of Brooklyn under NACA sponsorship. The study, presented in Technical Note 2226, includes a determination of the rigid-body frequency and damping characteristics of the coupled flapping and lagging oscillations of helicopter blades on which the lagging hinge axis is offset from the flapping hinge axis and both hinges are inclined. The effect of offset of the flapping hinge axis from the axis of rotation of the rotor is also considered.

The analysis and numerical examples indicate that significant increases in the damping of the lagging motions, which ordinarily border on instability, can be obtained by suitable inclinations of the hinge axis, particularly the lagging axis. Offsetting the flapping and lagging hinge axis also increases the natural lagging frequency.

UPPER ATMOSPHERE RESEARCH

The study of the compatibility of the tentative standard atmospheric temperature distribution as set forth in Technical Note 1200 with the observed free periods of oscillation of the atmosphere has continued. Technical Notes 2209 and 2314 present the results of a continued study of atmospheric tides by the Institute for Advanced Study, under NACA sponsorship. The investigations indicate that certain simplifying assumptions made in the development of the basic ocean tide equations invalidates these relations for application to the study of atmospheric tides. A method for including the previously neglected terms in the tidal equations has been outlined and two atmospheres of different temperature distribution have been studied.

A review by the Subcommittee on the Upper Atmosphere of experimental information on the characteristics of the atmosphere from sea level to a height of 32 kilometers has indicated that the standard atmosphere tentatively proposed in Technical Note 1200 represents to a satisfactory degree of accuracy the characteristics of the atmosphere within this height range.

POWER PLANTS FOR AIRCRAFT

With the ever-increasing trend for aircraft operation at higher altitudes and higher Mach numbers there has arisen a multitude of complex power plant problems. Efficient diffusers at high Mach number, greater air flow handling ability of compressors, increased combustion efficiencies at high altitudes without blowout or instability, increased turbine inlet gas temperatures, reduction of strategic material content, increased thrust augmentation with afterburners, and the over-all engine control and component matching require extensive power plant research. For the purpose of obtaining the most efficient operation of each part of the power plant, these problems have been approached through theoretical and experimental investigations. Power plants, such as the turbojet, the turbopropeller, the ram jet, the rocket, and combinations of these engines utilizing chemical and nuclear fuels are currently under investigation. As a result of this research improved subsonic and supersonic operation of the interceptor, the long-range bomber, and the guided missile can be expected.

NACA efforts in the aircraft-propulsion field have been assisted by the Committee on Power Plants for Aircraft and its seven subcommittees. The following discussion is limited to unclassified research.

AIRCRAFT FUELS RESEARCH

Intensive effort has been applied in the past year to the field of aircraft-fuel research with consideration being given to current aircraft fuels as well as fuels of the future. As might be expected, investigations conducted since the advent of jet propulsion have gradually led toward the development of special fuels for future power plants. Concurrently with research on future fuels it has been necessary to maintain a high degree of emphasis on current aircraft fuels in order to assure the availability of satisfactory fuels in the event of an emergency. The greatest problem in the current aircraft-fuel program is the formalization of a sound fuel specification that will assure maximum availability and superior performance.

Synthesis and Analysis

Because many of the aircraft considered for the future are volume-limited with respect to fuel storage, hydrocarbon synthesis has been directed primarily toward fuels that will release high energy per unit volume and consequently permit the attainment of desired flight range. Fuels of this type are not readily available even in small quantities required for research studies. For this reason synthesis facilities of the NACA are in continuous operation isolating pure high-density hydrocarbons to be used in engine-performance studies.

During the past year the synthesis and purification of some of the high-density hydrocarbons have been described in Technical Notes 2230 and 2260. Nineteen compounds were isolated and those having satisfactory physical and chemical properties will ultimately be evaluated in typical turbojet-combustor performance investigations. The synthesis projects are planned in an orderly manner to permit the analysis of correlations between molecular structure and properties. By this process considerable time and money is saved in that an examination of the correlation will indicate which molecular structures have obvious disadvantages, thus obviating costly and tedious synthesis.

In addition to high-density hydrocarbons, other compounds have been synthesized for investigation as possible fuel components to provide greater combustion stability over wide operating ranges and better ignition characteristics. Hydrocarbons such as cyclopropane derivatives are being prepared for study of the effect of molecular structure on rates of flame propagation. Results of the synthesis of ten cyclopropane hydrocarbons have been reported in Technical Notes 2258, 2259, and 2398. The ten hydrocarbons were obtained in high purity for the first time and physical constants and infrared spectra are given in the cited references. Synthesis procedures were developed, and physical properties and heats of combustion were determined for four alkylsilanes. This was the first experimental determination of heats of combustion for these compounds.

In the course of conducting synthesis projects, occasional results of general interest with regard to experimental technique are obtained. When this occurs, the data are published for the information and use of various synthesis laboratories. A study of this nature has recently been reported in Technical Note 2342. In this publication an evaluation of packed distillation columns used by the NACA is described.

Aside from the determination of physical properties of synthesized materials, the NACA analytical laboratories participate in studies to improve methods of analysis of fuels. Particular attention has been given to the analytical procedure for determination of aromatic and olefinic hydrocarbons in wide-boiling petroleum fractions. These hydrocarbon classes are known to be significant in relation to engine performance and therefore the quantities present in a given fuel stock must be accurately known. A procedure for the determination of aromatics and olefins has been developed which is applicable to the determination of aromatics and olefins in petroleum stocks with final boiling points below 600° F. Accuracies of 1 percent are attained with analysis times of less than 8 hours.

Fuels Performance Evaluation

The problem of relating easily measured hydrocarbon fuel properties to engine performance has received considerable attention since the advent of jet propulsion. The object of this research is to permit the prediction of engine performance of fuels from fuel properties that may be determined with relative ease. Combustion properties of interest are spontaneous ignition temperature, flame velocities, and inflammability limits.

Spontaneous ignition temperatures for 109 hydrocarbons and commercial fuels have been determined by a crucible method. From these data trends in the variation of ignition temperature with molecular structure have been established. The performance of ten of these fuels has been studied in a single tubular combustor.

During the past year flame-velocity studies were made of 37 pure hydrocarbons. The classes of compounds examined were alkanes, alkenes, alkynes, benzene, and cyclohexane. The results of this study indicated that the flame velocities of the normal alkanes were the same except for methane which had a velocity about 16 percent lower than the alkanes of higher molecular weight. The alkenes and the alkynes had velocities somewhat higher than those of the alkanes, particularly in the low molecular weight range. The results of this investigation have been published in the Journal of the American Chemical Society (vol. 73, No. 1, January 1951).

The flame velocity investigation was later extended to include the alkadienes. Ten compounds in this class were studied and it was found that the flame velocities were higher than those of the alkanes and approximately equal to the flame velocities of the alkynes investigated. Performance of certain fuels in these classes of compounds are being studied in a single tubular combustor.

The flame-velocity data accumulated in the foregoing investigations have been used as the basis for correlations between molecular structure and flame velocity. One such correlation indicated that the maximum flame velocity is a function of the concentrations of the various types of carbon-hydrogen bonds in the inflammable mixture. From this correlation the maximum flame velocities were calculated for 34 hydrocarbons. The average difference between the calculated and observed flame velocity is less than 2 percent. The results of this analysis were published in the Journal of the American Chemical Society (vol. 73, No. 4, April 1951).

As another part of this research an investigation is being conducted to determine the inflammability limits of pure hydrocarbon-air mixtures at different pressures. The limits were determined for 17 pure normal paraffins, branched paraffins, and mono-olefins. It was found that the lean inflammability limits were about the same for all of the fuels, however, the rich limits increased markedly with increased molecular weight.

The tendency of certain fuels to deposit carbon in combustors thereby lowering performance and causing mechanical difficulties continues as one of the more important problems for research. Brief investigations have been made of several fuels which contain components allowable in the jet fuel specification but which appear marginal from a carbon deposition standpoint. A study of these fuels with several current turbojet engines is intended to show how fuel specification and combustor design may be compromised for best performance and maximum fuel availability.

COMBUSTION RESEARCH

Because aircraft engines must produce enormous power from a small package, it is axiomatic that the combustion problem is to release tremendous quantities of heat energy from the fuel in a small volume and in a short space of time. NACA research on combustion is directed at obtaining an understanding of the basic physics and chemistry behind the phenomena involved in combustion and demonstrating how these phenomena can be put to use to meet all the requirements of flight. Basic studies are made on detailed problems of combustion such as evaporation, ignition, flame propagation limits, flame velocity, flame quenching, with variables such as composition, pressure, temperature, velocity, and turbulence. Studies on applying these data involve (*a*) systematic studies of the effect of operating variable and design variables on engine performance such as combustion efficiency, altitude operational limits, smoke and carbon formation, pressure drop and temperature profile, and (*b*) attempts to correlate basic combustion laws with engine performance.

Fundamentals of Combustion

To gain an insight into the problem of combustion stability at high altitudes, a study has been made of the chemical and physical factors affecting the inflammability limits at different pressures. The results of the investigation of chemical factors were discussed under the fuels research program. An investigation was also made of the effects of walls on inflammability limits. The results indicated that the minimum pressure for flame propagation increased with diminishing tube diameter (greater relative wall area). In connection with the inflammability limits of fuels, an investigation was conducted to determine the combustion efficiencies of hydrocarbon-air systems at reduced pressures. With quiescent fuel-air mixtures and with small diffusion flames, combustion efficiencies close to 100 percent were obtained at pressures much lower than those found in turbojet combustors at high altitude; in general, efficiencies were high at pressures approaching the limiting values for inflammation.

Several projects are in progress to ascertain the basic mechanism of flame propagation in order to gain insight into the actual combustion process that occurs in an engine. These studies supplement the studies of the effect of hydrocarbon structure on flame velocity reported in the fuels program. In one phase of this work, the effect of initial mixture temperature on flame velocity was evaluated. The first of these studies (Technical Note 2170) evaluated the flame velocities and blow-off limits of propane-air flames. These studies were later extended to include methane-air and ethylene-air flames (Technical Note 2374). As a result of these projects, equations were developed to permit the estimation of flame velocity at various initial mixture temperatures in the range of 34° to 344° C.

In order to achieve a better understanding of the cause of flame propagation, several studies have been made of the effect of free radicals on flame propagation. Inasmuch as hydrogen diffuses more readily than other radicals in a flame, it has been suggested by past investigators that the rate of flame propagation is related to the hydrogen-atom concentration in the flame zone. An evaluation of this theory was made by adding light water and heavy water to mixtures of carbon monoxide and air and measuring the flame velocities. It was reasoned that hydrogen from heavy water would diffuse less rapidly than that from light water; consequently, a lower flame velocity would result. Measurements of the flame velocities substantiated this reasoning.

In an analysis of flame-velocity data for 35 pure hydrocarbons, it was concluded that the maximum flame velocities were consistent with the active radical theory of flame propagation. Only one pure hydrocarbon, ethylene, was found to be inconsistent with the theory. This analysis was published in the Journal of the American Chemical Society (vol. 73, No. 1, January 1951).

In connection with flame-velocity investigations, a method for determining the distribution of luminous emitters in a Bunsen flame was found and is described in Technical Note 2246. As an example of the application of this method, an intensity distribution in a Bunsen cone image resulting from the free radical C_2 radiation was analyzed.

In order to correlate the flame-propagation velocities of a burner with the local turbulence intensity in the flow, quantitative turbulence data are needed. Such data have been obtained from an investigation, the results of which are presented in Technical Note 2361. Data were obtained for turbulent-velocity-fluctuation components and mean-velocity distributions in a subsonic jet issuing from a pipe in which fully developed turbulent flow was established. It was found that at the jet exit the axial-fluctuation-velocity component was about 2.5 times as great as the radial component at the pipe center line. Near the pipe wall, the axial-fluctuation-velocity component was about three or four times as great as the radial component. The axial components of the turbulent fluctuation velocities diminished rapidly downstream of the pipe wall, whereas the radial components were practically constant so that the axial and radial components approached a condition of equal magnitude with increasing distance from the pipe exit

LUBRICATION AND WEAR

Fundamentals of Friction and Wear

The current trend in the selection of aircraft-power-plant lubricants is to materials of low viscosity. The primary reason for this is to meet low temperature operating and starting requirements. It may be expected that such usage will lead to difficulties because of the low load capacities obtained with the light oils. One means of compensating for the reduced load capacity is by the use of EP (extreme pressure) additives. One of the objectives of lubrication and wear research is to determine for surfaces lubricated with EP additives whether a change in chemical reactivity could appreciably affect the rate of production of a protective film and thus appreciably affect the critical sliding velocity at which surface welding begins. Among the additives under study are benzyl chloride $C_6H_5CH_2Cl$, p-dichlorobenzene $C_6H_4Cl_2$, free sulfur S, benzyl disulfide $(C_6H_5CH_2)_2S_2$, and phenyl monosulfide $(C_6H_5)_2S$, at sliding velocities from 75 to 7,000 feet per minute and initial Hertz surface stresses up to 194,000 p. s. i. (Technical Note 2144). Results indicate that higher critical sliding velocities may be obtained with additives whose active atoms have the greatest chemical reactivity. The study showed that the factor of activity of the individual active atoms was more important than the number of such atoms available for reaction.

A further study of the effect of additives on critical sliding velocities involved the use of fatty acids (Technical Note 2366). This investigation was conducted because it has been found that with an EP additive lubrication may be ineffective at high sliding velocities because a chemical reaction between the surfaces and the additive to provide a lubricating film may not have time to occur. Further, studies at low temperatures have established the point that with the fatty-acid additive, high contact temperatures or pressures are unnecessary for the formation of an effective lubricating film. Studies have been completed of stearic acid as an additive in cetane at sliding velocities up to 7,000 feet per minute on clean steel surfaces and surfaces coated with ferric oxide Fe_2O_3 (Technical Note 2366). The experiments indicate that the type of surface oxide and the thickness of the oxide film are important in determining the effectiveness of stearic acid as an additive.

Most of the bearings employed in the turbine-type aircraft power plants are rolling-contact bearings. Early service experience indicated that one of the principal sources of failure in bearings has been lubrication failures at the cage locating surfaces (retainer or separator). These failures are due in main to the difficulty in obtaining proper lubrication because of design configurations and to "high-temperature soaking" (above 500° F.) of the turbine bearing after engine shut-down. One means of reducing the severity of the problem is to obtain a cage material having a lesser tendency toward metallic adhesion to steel under marginal conditions of lubrication than the currently used materials. Sliding friction experiments have been made to obtain fundamental comparative information on friction and wear properties which are a general measure of adhesion (Technical Note 2384). The materials studied were brass, bronze, beryllium copper, Monel, Nichrome V, 24S–T aluminum, nodular iron, and gray cast iron at sliding velocities up to 18,000 feet per minute. On the basis of wear and resistance to welding only, the cast irons were the most promising materials investigated in that they showed the least wear and the least tendency to surface failure when run dry. On the basis of mechanical properties, the nodular iron is superior to gray cast iron. Results obtained with brass, beryllium copper, and aluminum indicate that these materials are not particularly suited for cages.

It has been observed that the running of piston rings, particularly nitrided cylinder barrels, induces the formation on the ring of a surface coating which had different and, in some respects, superior properties compared with those of the bulk ring material. An investigation has been completed, whose objective was to determine to what extent these rubbing conditions could have produced transfer of metal from the barrel to the ring (Technical Note 2271). The study concerned itself with metal transfer between nitrided steel of several hardnesses and also between chromium plate and nitrided steel. The technique employed consisted of making one of two rubbing surfaces radioactive, carrying out a friction test and then examining the other surface for signs of radioactivity. The effects on material transfer of, load, speed, distance of travel, repeated travel over the same path, hardness of the moving surface, and the type of chromium plate were investigated. In the case of all materials studied, there was an observable amount of transfer. The amount of transfer was roughly proportional to the distance traveled and was independent of whether this travel was repeated a number of times over the same track or was continuously over fresh surface. In addition, the amount of transfer for a given distance of travel was constant over a range of low speeds, but started to decrease at higher speeds. This indicates that a possible pretreatment to obtain a desirable surface layer might consist of running rings in a special cylinder having walls of selected composition and controlled hardness to give surface coatings highly improved characteristics in a minimum length of time.

Fretting

Fretting is defined as the surface failure that may occur when closely fitting metal surfaces undergo slight relative motion. Recent research conducted by the NACA indicates that fretting is the result of localized or very concentrated friction phenomena. Adhesion is believed to be the primary friction phenomenon involved in that it causes the removal of finely divided oxidizable metal. Other phenomena, such as the rubbing off of oxide films, welding from frictional heat, and abrasion, undoubtedly contribute to surface destruction. The effectiveness of the intermetallic compound molybdenum disulfide (MoS_2) as a fretting inhibitor was studied, utilizing a steel ball, vibrated in contact with glass flats at 120 cycles per second, an amplitude of 0.001 inch, and a normal load of 0.2 pound (Technical Note 2180). A coating of dry molybdenum disulfide bonded to steel by rubbing a mixture of molybdenum disulfide and syrup in intimate contact with clean steel at elevated temperatures proved the most effective. This coating delayed the onset of fretting to 28,000,000 cycles in contrast to less than 30 cycles for a clean uncoated steel.

Bearing Research

A dependable bearing to carry a radial load at extreme speeds and at high ambient temperatures is desired for use as the turbine-support bearing in aircraft gas turbines where the gravity loads are usually under 1,000 pounds and the DN (diameter in millimeters multiplied by revolutions per minute) values are as high as 1×10^6. To develop such a bearing it is necessary to know the operating characteristics and limitations of conventional rolling-contact bearings at high speeds and how these characteristics and limitations may be improved and extended by such means as improved lubrication methods and design modifications. A study has been completed utilizing three types of bearings to determine experimentally the operating characteristics of conventional cylindrical roller bearings at high speeds at DN values from 0.3×10^6 to 1.65×10^6 and static radial loads from 7 to 1,613 pounds with circulatory oil feed (Technical Note 2128). The operating temperatures of the bearings were found to differ most appreciably in the low-load high-speed range where the roller-riding cage-type bearing exhibited significantly lower operating temperatures than the one- and two-piece inner-race-riding cage-type bearings. However, the operation of the roller-riding bearings was considerably rougher than that of the inner-race-riding bearings and they showed prohibitive cage and roller wear.

A continuation of the study outlined above was undertaken to compare and to evaluate the effects of oil-inlet location, jet angle, and jet velocity on outer- and inner-race bearing temperatures for single-jet lubrication over a wide range of variables (Technical Note 2216). The effect of oil flows of 0.6 to 12.9 pounds per minute and oil inlet velocities of 13 to 200 feet per second were studied utilizing a one-piece inner-race-riding brass cage bearing over a load range of 113 to 368 pounds and DN values of 0.3×10^6 to 1.43×10^6. For the conditions studied, the inner- and outer-race temperatures were found to be at a minimum when the oil was directed at the cage-locating surface perpendicular to the bearing face. A mathematical correlation based on heat transfer considerations was obtained such that for a given operating condition a representative single straight line resulted regardless of whether the bearing speed, oil flow, or jet diameter was varied.

COMPRESSOR AND TURBINE RESEARCH

Compressor Research

Both high-speed and long-range aircraft utilizing gas-turbine power plants require light compact compressors with large air-flow capacities and high pressure ratios and efficiencies. Compressor research, therefore, is being directed toward solving aerodynamic problems of compressing air efficiently in a compressor of minimum frontal area, minimum length, and minimum complexity, so that the unit will be mechanically sturdy and easily manufactured. A reliable engine having comparatively low initial cost can thus be obtained. Compressor research consists of theoretical work on compressor aerodynamics, guide vane studies, cascade investigations, and single-stage and multistage compressor investigations.

The theoretical approach to the aerodynamics of compressors has been concentrated on obtaining a working knowledge of the flow phenomena associated with the compressor and its operating conditions. As an approach to the solution of the three-dimensional flow through compressors, a general through-flow theory corresponding to axially symmetric flow has been developed (Technical Note 2302). The theory is applicable to both *direct* and *inverse* problems and is derived primarily for use in machines having thin blades of high solidity.

In order to approximate the circumferential variation of the flow conditions, which is neglected in the through-flow solution, several different approaches have been used. When the radial component of flow is negligible, the flow follows along cylindrical surfaces and may be analyzed in terms of the equivalent two-dimensional cascade. The method developed for designing cascade blades (Technical Note 2281) with prescribed velocity distribution for subsonic compressible flow based on a linear pressure-volume relation has been extended, and expressions for estimating the accuracy of solutions have been developed.

For cases where the radial component of velocity is not negligible, a better approximation to the actual flow is obtained by assuming the flow to take place along the surfaces of revolution, as obtained from the axially symmetric solution, and then determining the flow between the blades along these surfaces of revolution. Both the direct and inverse problem for subsonic flow have been analyzed (Technical Note 2407).

A rapid but approximate blade-element-design method (Technical Note 2408) for compressible or incompressible nonviscous flow in high-solidity stators or rotors of axial-, radial-, or mixed-flow compressors has been developed. The method is based on channel-type flow between blade elements on a specified surface of revolution that lies between the hub and shroud and is concentric with the axis of the compressor. The blade element is designed for prescribed velocities along the blade-element profile.

The characteristic equations for the axially symmetric flow in supersonic impellers have been developed and used to investigate flows in several configurations in order to ascertain the effect of variations of the boundary conditions on the internal flow and work input (Technical Note 2388).

A theoretical discussion of the application of blade boundary-layer control to increase the efficiency and the stage pressure ratio and to improve off-design performance of turbomachines is given in Technical Note 2371. Also presented is a method based on potential flow of a compressible fluid for designing suction, or ejection slotted, blades having a prescribed velocity distribution along the blade and in the slot.

The boundary-layer profiles on the casing of an axial-flow compressor were measured behind the guide vanes and behind the rotor. Using these measurements and three-dimensional boundary-layer momentum-integral equations which were developed (Technical Note 2310), a qualitative consideration of boundary-layer behavior on the walls of an axial-flow compressor was made. This consideration shows that the important parameters concerning the secondary flows in the boundary layers are the turning of the flow and the product of the curvature of the streamline outside the boundary layer by the boundary-layer thickness.

Turbine Research

The problems associated with the turbine component of the turbojet engine are similar to those of the compressor when good performance is required for application to transonic and supersonic aircraft. The problems in obtaining light, efficient, and dependable turbine components for driving compressors are in general the result of compromising the turbine aerodynamics with mechanical considerations to obtain reasonable stresses. The turbine research is therefore being aimed at improving the turbine performance. Turbine cooling is also commanding considerable attention as a means of improving the compromise between the requirements of stress and aerodynamics. Turbine research consists of theoretical turbine aerodynamics in which the theories and tools developed for compressors are readily applicable, cascade investigations, and single-stage and multistage turbine research.

In order to facilitate the determination of the best design compromises in the design of turbines, a method was developed for the computation and graphical presentation of a series of possible turbine designs for any specific application. Design charts are made to aid in the study of the effects of turbine radius ratio and diameter on important design parameters such as Mach number, turning angle, and blade root stress. The method for constructing these charts is presented in Technical Note 2402.

Non-twisted-type rotor blades are desirable where internal passages in the blades are required for turbine cooling. An analytical evaluation has been made of the aerodynamic characteristics of turbines with non-twisted rotor blades by comparison with the corresponding characteristics of free-vortex turbines. The results of this investigation, including working charts for aid in designing non-twisted-rotor-blade turbines, are presented in Technical Note 2365.

Turbine Cooling

The research program for the application of cooling to gas turbines has two objectives. The first is the elimination of critical metals from the turbine rotor of gas-turbine engines so that alloy steels of higher strength and lower critical material content can be used while extending the useful life of turbine blades. The second objective is to provide the means of operating gas turbines at higher gas temperatures to achieve the large potential gains in thrust of the turbojet engine, and the increase in power and the lower specific fuel consumption inherent in the turbine-propeller engine. Past analyses and cascade investigations show that the blade-temperature reduction required to permit substitution of noncritical metals can be achieved with acceptable coolant flow.

Solutions for a system of generalized equations for the laminar boundary layer with heat transfer have been developed for the determination of local heat-transfer coefficients. Numerical solutions have been obtained for low Mach numbers over a wide range of coolant flow, temperature ratio, and pressure gradient with allowance for fluid property variations. Solutions to the equations for the high Mach number range are now being effected through the use of automatic computing machines (Technical Note 2207).

Analytical methods for computing one-dimensional spanwise or chordwise temperature distributions in liquid-cooled turbine blades or in simplified shapes used to approximate sections of liquid-cooled turbine blades have been summarized (Technical Note 2321).

Blade Vibration and Flutter

An experimental spin rig was used to determine the effect of root design on the damping of loosely mounted blades. The conventional ball-and-dovetail roots were shown to have the same characteristics in that tightening occurred at relatively low values of centrifugal force, thus eliminating the advantages of the loose fit. The fir-tree and the hinge designs, however, had different characteristics, the fir-tree tightening at the relatively high centrifugal loadings and the hinge root remaining loose throughout the speed range investigated.

Methods have been developed for computing the natural modes and frequencies of arbitrarily shaped twisted cantilever beams. Use has been made of the concept of station functions. An analysis is being made by this method to compute the natural modes and frequencies of a group of different compressor and turbine blades. The computed values will be compared with experimental values in order to evaluate the analytical method (Technical Note 2300).

ENGINE PERFORMANCE AND OPERATION

Performance and Operating Characteristics

The performance of turbojet, turbopropeller, and ram-jet engines has been investigated over a range of altitudes and flight Mach numbers. In addition to obtaining altitude performance characteristics, the effects of Reynolds number, burner blow-out limits, altitude starting characteristics, and component performance were studied. As a result of these investigations basic design changes were recommended which result in improved power plant performance for future engines. Various principles of thrust augmentation have been evaluated experimentally under a variety of engine operating conditions.

An analysis was made to obtain an expression for the optimum jet-pressure ratio for any turbine-propeller engine. The results of this analysis, reported in Technical Note 2178, are presented in the form of charts from which the jet-pressure ratio for the division of power giving maximum thrust may be obtained for engines either with or without intercooling, reheat, regeneration, or any combination of these modifications.

Analytical evaluations of different methods of power extraction from an axial-flow-type turbojet engine have been completed. These results have been presented in terms of generalized parameters that facilitate their application to different engines. The data cover the range of power extractions available from the engines on a range considered ample for all auxiliary-power requirements. The power-extraction methods are compressor-outlet air bleed, shaft-power extraction, turbine-inlet or tail-pipe hot-gas bleed, and the use of a tail-pipe heat exchanger on a turbojet engine as an auxiliary power (or energy) source. The first three parts of this investigation are reported in Technical Notes 2166, 2202, and 2304.

Engine Controls

A variety of engine control loops have been evaluated experimentally to determine effects of interaction and stability on engine operation. Several theoretical studies were conducted to determine optimum control arrangements for various engine types.

An analysis was made of the effect of independent variations in the component efficiency characteristics, flight conditions, and engine size on the time constant and the turbine-inlet-temperature overshoot of a turbojet engine with a centrifugal compressor and a turbine with choked stator. The dynamic factors were calculated from the thermodynamic equations of engine-component performance. This investigation is reported in Technical Note 2182.

The general form of transfer functions for a turbojet engine with tailpipe burning was developed and the relations among the variables in these functions were found from the transfer functions and from engine thermodynamics (Technical Note 2183). By means of these relations, the dynamic characteristics of the engine can be found from steady-state data and one transient relation.

As reported in Technical Note 2378, a rational analytic method for the design of automatic control systems was developed that starts from certain arbitrary criterions on the transient behavior of the system and derives those physically realizable characteristics of the controllers that satisfy the original criterions.

Accurate knowledge of the dynamic response characteristics of turbine-propeller engines and the factors that affect these characteristics are of great importance in the design of quick-acting, stable controls for this type engine. An investigation of the dynamics of a turbine-propeller engine was made at sea level (Technical Note 2184) and in the altitude wind tunnel employing the frequency-response technique for a range of altitudes.

Directing research effort toward the improvement of the turbine-propeller engine requires an appreciation of the relative importance of the various engine-component characteristics. An analysis is being made to determine the influence of interdependent characteristics, such as component size, efficiency, and flow capacity, on the performance of the turbine-propeller engine. Results are evaluated on an airplane-performance basis so as to reveal the ultimate effects of the variables under investigation.

Thrust Augmentation

A theoretical analysis of thrust augmentation of turbine-propeller engines is in progress. Methods of augmentation considered are tail-pipe burning, compressor-inlet water injection, and a combination of water-injection and tail-pipe burning. Augmented performance with tail-pipe burning has been determined for high subsonic and for supersonic speeds. Calculations are in progress on the augmented performance with water injection over a range of flight conditions from take-off to transonic flight at altitude, and on the performance at high speeds with a combination of water injection and tail-pipe burning.

An analysis is being conducted for the prediction of the jet flows, pumping characteristics, and jet thrust obtainable from conical ejectors in order to determine the rules for the design of such ejectors for maximum effectiveness. A one-dimensional analysis of conical-air-ejector performance was made using an assumed pressure gradient along the conical secondary shroud.

ENGINE MATERIALS RESEARCH

High Temperature Materials

As a part of the search for materials having physical properties suitable for use at higher and higher operating temperatures, considerable effort is being expended in trying to improve the physical properties of the current materials. Factors which influence the high temperature strength of alloys are melting practice, forging, or casting procedures, and the heat treatments selected. To gain a better understanding how heat treatment affects the structures of alloys and the resulting physical properties, studies have been conducted of the fundamental factors which control the properties of austenitic alloys having exceptionally high creep and rupture strengths in the temperature range of 1,200° F. and 1,500° F. Such a study has been completed on Inconel X (Technical Note 2385). Correlations of the mechanical properties with structural analyses were made. It appeared from the study that aging resulted in some improvement in rupture strength in the range from 100–1,000 hours rupture time at 1,200° F. This improvement was obtained apparently through increasing the resistance to creep prior to fracture. This is in contrast to results obtained with N–155 wherein the improvement appeared to be through the formation of a grain boundary phase.

As a part of the study of the conservation of strategic materials for aircraft engines, efforts are being directed toward the evaluation of substitute materials of reduced alloy content. Among the materials studied for sheet applications is AISI 310B (Technical Note 2162). One of the draw-backs of this material has been low ductility in the temperature range from 1,200° F. to 1,400° F. The objective of this research was to determine whether service at 1,700° F. to 1,800° F. would cause increased brittleness at 1,200° F. to 1,400° F. with resultant cracking during heating and cooling. Stress rupture tests were made in the 1,200° F. to 1,400° F. range with a few tests at 1,700° F. and 1,800° F. Among the variables considered were heat-to-heat reproducibility, the relative effects of annealing, and hot and cold working as initial treatments. It was found that the elongation at 1,300° F. was increased by prior heating from 1,700° F. to 2,000° F. In addition, it was determined that the cold-rolled stock had the lowest ductility.

Inasmuch as several of the important high-temperature alloys utilize both chromium and cobalt and because a number of the physical properties of an alloy are controlled by diffusion processes within the alloy in the solid state, an investigation was conducted to determine the diffusion coefficients of chromium in the alpha cobalt-chromium solid solutions (Technical Note 2218). The method employed consisted of pressure-welding cobalt and cobalt-chromium bars, annealing these joined bars at constant temperatures and determining the distribution of chromium through the diffusion zones thus formed. It was found that the diffusion coefficients at 1,000° C., 1,150° C., 1,300° C., and 1,360° C. were relatively constant. It was further found that chromium diffusivity from alpha cobalt-chromium alloys into cobalt is greater than chromium diffusivity from high-chromium alpha alloys to low-chromium alpha alloys for all concentration gradients studied.

Studies of the properties of molybdenum at high temperatures have been continued. The effects of swaging, recrystallization, and "test-section" area on the strength properties of sintered wrought molybdenum were determined at temperatures from 1,800° F. to 2,400° F. (Technical Note 2319). The amount of swaging on the specific bar sizes investigated had little effect on the tensile strengths, but increasing amounts of swaging progressively lowered the recrystallization temperature. Increasing the test-section area of a specimen had a negligible effect on the tensile strength. Wrought molybdenum had a 100-hour stress-rupture life of approximately 19,300 ± 300 p. s. i. at 1,800° F.

Studies of ceramic coatings for the protection of ceramals and less strategic alloys from high temperature oxidation and corrosion have led to the development of a ceramic coating with a high chromium metal content. Evaluations of these coatings on a TiC base ceramal have demonstrated the ability of the coating to protect against oxidation as well as its ability to withstand small elongations and severe thermal shock (Technical Notes 2329 and 2386). It was found that in general the best protection was obtained in oxidation tests at the higher temperatures. Studies of the effects of firing time, firing temperature, and the number of coatings applied indicated that there is an optimum firing time and firing temperature. For the coating studied, two applications proved superior to one.

Studies of the effectiveness of ceramic coatings in preventing high temperature corrosion by lead-bromide vapors indicate that the ceramic coatings appeared to be inert to the $PbBr_2$ and successfully inhibited corrosion of the alloys studied for a 6-hour test period (Technical Note 2380). The alloys S-816, HS-21, Inconel, 19-9DL, and AISI 347 were tested (*a*) in an uncoated condition, (*b*) in a preoxidized condition, and (*c*) in a coated condition when exposed to the lead-bromide fumes in an air atmosphere at 1,350° F., 1,500° F., and 1,650° F.

As a part of the general program for the evaluation of ceramals, investigations have been completed of the bonding of TiC with Al, Be, Cb, Au, Fe, Pb, Mg, Mn, Pt, Ti, and Va (Technical Note 2187). The test procedure consisted of placing powdered metal in a cup-shaped depression formed in a hot-pressed TiC test bar, inserting the specimen in a furnace at temperatures up to 3,650° F. Studies were made of the sectioned specimens to determine what kind of bonding, if any, took place. Of the elements studied, only nickel, cobalt, chromium, and silicon bonded with titanium carbide. There was some indication of a limited solubility of titanium carbide in nickel and cobalt.

A continuation of the study outlined above was conducted, utilizing zirconium carbide and columbium to determine the bonding mechanism (Technical Note 2198). The results indicated that the mechanism is one in which columbium atoms diffuse into the zirconium-carbide lattice, displace zirconium atoms, and form zirconium metal and a completely soluble columbium carbide. This results in a homogenous solid solution of the zirconium-carbide matrix and the columbium carbide. The size and the distribution of the metal phase was controlled by sintering time and temperature. In general, the specimen with a fine dispersion of metal had the highest strength.

Stresses Research

The failure of turbine and compressor blades due to vibrations has led to an increased interest in the determination of the natural modes and frequencies. Assuming a compressor or turbine blade acts as a cantilever beam, a method has been developed for calculating the coupled modes (Report 1005). The method is based on the concept of Station Functions and permits the calculation of the modes and the frequencies of nonuniform cantilever beams vibrating in torsion, bending, and coupled bending-torsion motion. Results of the application of this method show that the effect of coupling between bending and torsion is to reduce the first natural frequency to a value below that which it would have if there were no coupling.

In the design of a turbine rotor it is desirable to know the detailed stress and strain distributions in the strain-hardening range and the amount of increase in load that can be sustained between the onset of yielding and failure. A simple method of solving the plane-stress problems with axial symmetry, employing the finite strain concept in the strain-hardening range, and based on the deformation theory of Hencky and Nadai, has been derived for the condition that the directions and ratios of the principal stresses remain constant during loading (Technical Note 2217). The results indicated that the ratios of the principal stresses remain essentially constant during loading and, therefore, the deformation theory is applicable to this type of problem. In general, it may be said that the deformation that can be accepted by the member before failure depends primarily on the maximum octahedral shear strain of the material.

In the design of high-stressed machine parts, a knowledge of the stress and strain concentration due to a hole and also of the distributions of stresses and strains in the strain-hardening range is desirable. As a continuation of the work reported above, a linearized solution has been obtained for the problem of plastic deformation of a thin plate with a circular hole in the strain-hardening range (Technical Note 2301). This solution is based on the deformation theory of plasticity for finite strains. The results indicate that the data obtained by the linearized method compare closely with those obtained without linearization. In addition, it was found that the solution for an ideally plastic material with the infinitesimal strain concept gives good approximate values of strains but not of stresses.

A further study of the distribution of stresses and strains in the strain-hardening range has led to a partly linearized solution of the plastic deformation of a rotating disk considering finite strains (Technical Note 2367). The results indicate that the variation of a parameter, which is determined from the octahedral shear stress-strain curve of the material, can be used as a gen-

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eral criterion of the applicability of the deformation theory. In addition, it appeared that the rotating speed of a disk for a given maximum strain of the disk can be determined directly from the true tensile stress-strain curve of the material.

A continuation of the investigation reported in Report 1005 has been completed to determine the effect of twist on vibrations of cantilever beams (Technical Note 2300). It is shown that for a beam with a ratio of bending stiffness in the two principal directions equal to 144, the effect of coupling due to twisting is to raise the value of the first natural frequency by a very small amount, to decrease steadily the second frequency, and to lower the third frequency considerably.

A significant question to be considered in the specification of chemical composition and mechanical and thermal treatment of a rotor disk is the compromise between ductility and tensile strength. An investigation was conducted to determine the strength-reducing effects of several types of irregularities, various ductilities, and an optimum compromise between ductility and the tensile strength in the presence of such defects (Technical Note 2397). The strength of disks containing irregularities increased with increasing tensile strength independently of ductility at ductilities in excess of 14.9 percent elongation. The best compromise between ductility and tensile strength in material containing shrink porosity occurred at 6.8 percent elongation.

The application of X-ray diffraction techniques to a study of stress analysis indicates that the back reflection techniques will yield a reasonable strain accuracy under favorable conditions. Because the conventional experimental methods reduce the precision in determining interatomic spacing and restrict the analysis to those materials which yield a reasonably sharp diffraction pattern, a new technique and camera have been devised (Technical Note 2224). A calibration of the camera, using a gold powder standard having a reported atomic spacing of 0.91008A, yielded an accuracy of atomic spacing of approximately $\pm 4\times10^{-5}$A. A comparison of the new technique with the results obtained from the conventional equipment and techniques indicated that a more precise and detailed analysis of atomic strain could be obtained.

ROCKET RESEARCH

The major problems of rocket research are to select fuel and oxidant combinations that give large thrust per unit weight flow and volume flow and still have properties that permit their handling and use, to prevent failure of the engine from high temperatures attained, to achieve efficient combustion in the smallest possible unit, and to evaluate the optimum application of rocket propulsion.

Rocket Propellants

Investigations of rocket-propellant performance are usually preceded by theoretical analyses of the performance of various fuel-oxidant combinations. These analyses are used as a basis for selecting the propellants worthy of experimental evaluation. Compilation of the thermodynamic functions to be used in these analyses has been continued.

An analysis was made to show the relative importance of specific impulse and propellant density on missile performance. The analysis compares propellant combinations having different specific impulses and densities by determining the least gross weight of a missile to accomplish a given mission.

Rocket Combustion

A basic study of the hydraulic characteristics of injection systems was started as an aid in establishing the relation between injector method and combustion characteristics. Initial studies of two impinging jets of water revealed that the spray disintegrates into groups of drops which for the conditions existing in a rocket correspond to frequencies observed in combustion fluctuations. These results are reported in Technical Note 2349.

AIRCRAFT CONSTRUCTION

The NACA is continuing its efforts to enlarge the scope and the amount of its research on airframe construction problems. The need for such an increase in effort has been previously pointed out and the manner in which it is to be accomplished is under study.

Programs during the past year have included extensive laboratory and flight research and the continued collection of statistical data on gust loads encountered in regular airline operation. All airframe construction problems have been complicated by the increasing altitude and speeds of flight and these two factors can be found at the root of most new structural design problems.

As in the past, a considerable amount of the NACA research on structural materials and structures was performed under contract at universities and other nonprofit scientific organizations.

In accordance with the policy of holding technical conferences with representatives of the military services and the aircraft industry, a conference on aircraft loads and structures was held at the Langley Laboratory in the spring of 1951.

A description of the Committee's recent unclassified research on airframe construction is given in the following pages and is divided in four sections: Aircraft loads, structures, vibration and flutter, and aircraft structural materials.

AIRCRAFT STRUCTURES

Stress Distribution

Experimental investigations have shown that the stresses and distortions arising at the wing-fuselage juncture of swept wings are appreciably different from those occurring in straight wings. Some theoretical work showing the effects of sweep-back on the deflection of box beams under bending and torsion loadings had been published, but there was a need for an analysis giving the stresses at the triangular root section of a swept box beam. Accordingly, a method presented in Technical Note 2232 was developed for analyzing the triangular portion of the box beam and for establishing continuity between this section and the carry-through section, as well as the outboard portions of the box beam. The results obtained by this method were compared with previously published test data. The agreement was found to be fair, with the principal discrepancy being due to the fact that the method is based on a very simple type of idealized structure which prevents the appearance of shear lag in the results. An extension of the basic approach was therefore made in order that it might include the effects of shear lag.

Exact solutions for the stresses and deformations in wings subjected to torsion are not easily obtained. Oregon State College has therefore developed an approximate method of solving for the angle of twist, longitudinal stresses, and shear stresses in torsion boxes of rectangular, elliptical and airfoil cross sections. The results of these theoretical studies indicate trends for consideration in design.

For proper design of cut-outs that occur in stiffened-shell structures, a detailed knowledge of the redistribution of stresses around the cut-outs is necessary. An approximate theory had been developed for the analysis of stresses in torsion boxes containing large cut-outs which is adequate for the design of all components of such structures except the cut-out cover. This theory was extended in Technical Note 2290 to permit a more detailed calculation of the stresses in the cover. Numerical results were compared with experimental data and also with the results of a solution made by a more elaborate numerical procedure. The agreement was found to be satisfactory in all cases except those with very large cut-outs and flexible bulkheads.

For analysis of thin solid wings of small aspect ratio, such as might be used in supersonic airplanes and missiles, beam theory is no longer adequate. Wings of this type are more nearly plates than beams and can be analyzed by plate theory. However, solutions to the partial-differential equations of plate theory are not readily obtained, especially for plates of arbitrary shape and loading. A method is presented in Technical Note 2369 for obtaining ordinary differential equations to replace the partial-differential equations. This simplified plate theory has been applied to specific problems involving static deflection, vibration, and buckling of cantilever plates.

One proposed method for increasing the storage space inside a wing is to replace the ribs with a number of vertical posts connecting the compression and tension covers of the wing box beam. A theoretical study of an idealized post-box configuration had indicated that the compression cover of a box beam could be stabilized by posts with an attendant weight saving. In order to check the validity of the theory developed, a beam was tested and the results reported in Technical Note 2414. The experimental buckling load was in good agreement with theory, but appreciable distortion of the beam cross section occurred before the buckling load was reached. It was concluded that a proper combination of posts and ribs may make a design that would be satisfactory with regard to both deformation and strength.

The skin on the upper surface of a wing is subjected to compression by the bending of the wing, and in most cases the addition of stiffening elements to the skin is required to enable the compression load to be carried. Direct-reading design charts have been prepared for 75S–T6 aluminum alloy flat compression panels having longitudinal extruded Z-section stiffeners. These charts, which are presented in Technical Note 2435, cover a wide range of propositions and make possible the direct determination of panel dimensions required to carry a given intensity of loading with a given skin thickness and effective length of panel. They also make possible the determination of the panel proportions having minimum weight and meeting the design conditions.

A type of sandwich plate widely used in airplane construction consists of a corrugated metal sheet riveted between two metal face sheets. In order to apply existing sandwich-plate theories to the analysis of the corrugated-core sandwich plate, a knowledge of certain elastic constants which describe the distortions of the sandwich plate under simple loadings is required. Formulas for evaluating these elastic constants for the corrugated-core type of sandwich have therefore been derived and presented in Technical Note 2289. Suggestions have also been made as to the method of extending existing sandwich-plate theory to make it strictly applicable to the unsymmetrical type of corrugated-core sandwich.

Pressurized cabins of high-altitude airplanes present many stress analysis problems unusual to the aircraft field. These problems have been reviewed by Stanford University and a report containing a summary of the available information on these problems has been prepared.

The ultimate load-carrying capacity of stiffened-shell structures which are subjected to combined loads is a subject on which little information is available. In order to investigate one phase of this problem, a series of five large stiffened circular cylinders was tested to failure under various combinations of torsion and compression. An interaction curve for the strength of stringers that fail by local crippling was determined, and data were obtained on stringer stresses for stiffened cylinders under combined loads. The test results and a method for estimating stiffener stresses are presented in Technical Note 2188.

Stability

In 1947 Shanley showed that it was possible for a straight column in the plastic stress range to start to bend at a load given by the Euler formula with the tangent modulus of elasticity substituted for Young's modulus of elasticity. He also pointed out the existence of a maximum column load which was greater than the tangent-modulus load. In order to determine the amount by which the maximum load could exceed the tangent-modulus buckling load, a study of column behavior in the plastic stress range was undertaken, the results of which are reported in Technical Note 2267. This study confirmed the existence of the tangent-modulus buckling load, and showed by a rigorous load-deflection analysis the relation of the maximum load to the stress-strain curve of the material.

A thin-walled fuselage may buckle either by deformation of the entire column (column buckling) or by deflection of its component webs and flanges (local buckling). Methods are available for the determination of the buckling load for each mode of failure, and it is common practice to assume that a column will fail at the lower of the two loads in a mode corresponding to this load. In reality, however, there is an interaction of these two modes of buckling so that the actual buckling load is smaller than that which is ordinarily used. An investigation has therefore been conducted by Cornell University for the purpose of determining the interaction effect between column and local buckling. The results of this study indicate that this effect is negligible for box sections and for common sizes of I, H, and channel sections but may be significant for sections possessing torsional instability, such as T and angle shapes.

A method has been developed by the National Bureau of Standards for computing the compressive load for lateral elastic instability of hat-section stringers and is presented in Technical Note 2272. Applying the method to a range of shapes and lengths of hat-section stringers shows that such stringers are unlikely to fail by lateral instability.

The use of swept wings and tail plan forms with ribs placed parallel to the flight path results in sheet panels that are parallelogram-shaped. Few data exist on the stability of such panels under the loadings that arise due to wing and tail bending. Accordingly, in Technical Note 2392 charts have been prepared giving theoretical compressive-buckling-stress coefficients for continuous flat sheet divided by nondeflecting supports into parallelogram-shaped panels. Over a wide range of panel aspect ratio, such panels are decidedly more stable than equivalent rectangular panels of the same area.

Thermal Effects

The determination of the structural effects of nonuniform temperature distributions, such as might be produced by aerodynamic heating, is rapidly becoming a problem of interest to aircraft designers because nonuniform temperature distributions have important and complex effects on the stresses and distortions of the structure. The calculation of the stresses due to nonuniform temperature distributions has been treated by several investigators, since the problem has long been of concern to power-plant designers; however, methods that would be directly applicable to the thermoelastic analysis of aircraft structures are not yet available. Two preliminary studies have therefore been completed on this subject. The first, reported in Technical Note 2240, considers the two effects of temperature changes on aircraft structures: The introduction of thermal stresses and distortions as a result of restrained thermal expansion, and the change in behavior of the structure resulting from the variation of elastic properties of materials with temperature. These effects have been illustrated by sample analyses of the stress and distortion distributions of simple box beams and by calculation of the stresses in a typical wing section. The analytical methods of the first study provide a relatively simple means of approximating the effects of temperature changes; however, they often yield inaccurate values for the secondary stresses in complicated structures, and in such cases some numerical approach is desirable. The second study, reported in Technical Note 2241, extends a previously published numerical method of stress analysis to include the effects of a nonuniform distribution of temperature. An illustrative analysis using this method was made of a two-cell box beam under the combined action of vertical loads and a nonuniform temperature distribution.

Syracuse University has conducted an experimental investigation of the temperature and stress gradients resulting from the application of heat to the skin of a number of skin and spar cap combinations. The 75S–T6 aluminum alloy specimens with a range of skin thicknesses were heated at various rates to provide a better understanding of heat flow through high-speed aircraft wings.

Fatigue

An investigation is being conducted on the fatigue strength of full-scale airplane structures. The results, to date, indicate a surprisingly small amount of spread in the fatigue life even though all the fatigue cracks do not originate at the same point. Effective stress-concentration factors have been computed and compared with results from tests of small laboratory specimens. The importance of fatigue crack length on crack growth is pointed out in these tests. In connection with this work the structural damping of a typical airplane wing has been determined. These measurements were carried out by the shock-excitation method, with the resultant frequency of vibration being that of the wing fundamental bending frequency. The results are in agreement with those of other experimenters who have measured structural damping of smaller wing specimens. They indicate that the damping increases with amplitude of vibration.

AIRCRAFT LOADS

Steady Flight Loads

A simplified lifting-surface theory has been applied to the problem of evaluating span loading due to flap deflection for arbitrary wing planforms (Technical Note 2278). A procedure was developed from which the effects of flap deflection on span loading and associated aerodynamic characteristics can easily be computed for any wing that is symmetrical about the root chord and that has a straight quarter-chord line over the wing semispan. The effects of compressibility and spanwise variation of section lift-curve slope are taken into account by the procedure. The load distribution and lift due to flap deflection were prepared in chart form for a broad range of wing planforms for the case of straight tapered wings and a comparison between experimental values of flap effectiveness and values obtained from these charts show good agreement between theory and experiment.

Maneuvering Loads

As airplanes increase in size and weight, experimental data must be obtained to evaluate current maneuvering tail-load design requirements and to assist in extrapolation to the larger airplanes. The need for data arises from the variations in the response of the airplane as size increases, and also because a pilot's mental attitude and his control actions will vary according to the size and type of airplane. In view of the gaps in existing data a joint project for flight testing the Lockheed Constitution (design gross weight 184,000 pounds) was conducted by the Navy Department, Bureau of Aeronautics, and the NACA.

These tests, reported in Technical Note 2490, indicated that the analytical process of estimating the maneuvering tail loads for a large airplane need be little different from that for small airplanes. The flexibility of the tail had a minor effect on the estimated tail load and the resulting response of the airplane. Because of the relatively slow response of the airplane, the pilot was forced to anticipate the airplane response in applying control forces; for this reason the pilots often unknowingly obtained undesirably high load factors. The pilots were unaware of the critical tail loads arising from abrupt restoration of the control to neutral during a pull-up or sideslip. Pilots also expressed the opinion that the rolling pull-out maneuver felt similar to maneuvers required to recover from disturbances to flight in rough air.

Gust Loads

The dynamic behavior of an airplane wing during flight through rough air was investigated by flight tests on a twin-engine transport airplane. Results from flights made in clear-air turbulence were compared with results from slow pull-ups made in smooth air used as a quasi-static reference condition (Technical Note 2424).

As an extension of previous investigations of the effect of sweep on gust loads, tests were made in the Langley gust tunnel on a 60° swept-back-wing model to determine the effect of a large angle of sweep on gust loads. The results indicate that a simplified method of analysis, using a slope of the lift curve derived by the cosine law and strip theory to estimate the penetration effect is applicable to the prediction of gust loads on wings swept as much as 60°. These results as well as a summary curve representing the results of investigations with wing models having from 45° sweep-forward to 60° sweep-back are presented in Technical Note 2204.

An instrument to indicate atmospheric turbulence has been constructed and subjected to laboratory and flight tests. The design of the instrument was based on previous findings that the rapid fluctuations of the air speed in gusty air constituted a measure of atmospheric turbulence. The instrument consists essentially of a vented air-speed diaphragm in a sealed case with the lag characteristics of the vent chosen so that the diaphragm responds to the rapid changes in dynamic pressure in gusty air but remains insensitive to gradual changes resulting from normal air-speed changes. The results of flight and laboratory tests indicate that the principle of design was a practicable one, but further design refinement would be necessary if the instrument were to be used in routine airplane operations.

The effect of atmospheric turbulence on the loads encountered by aircraft in operational flight has been studied for some time by analyzing records secured with the NACA V–G (airspeed-acceleration) recorder. The instrument originally employed was troublesome to adjust and was limited in frequency response. An improved recorder has been developed which employs a viscous-damped accelerometer. Improved frequency response of the accelerometer has resulted and the necessity for adjusting damping in the field has been eliminated. The motion of the air-speed element has been made approximately linear with air speed; in addition, the element has been temperature-compensated. The new NACA oil-damped V–G recorder and its performance characteristics are described in Technical Note 2194, and the results of tests which demonstrate improvements to the older design are presented.

The NACA VGH recorder described in Technical Note 2265 is a flight instrument designed to collect gust-loads data on transport aircraft with the accuracy required for research purposes. Air speed, normal acceleration, and altitude are recorded on photographic paper as a function of time and in the usual applications 100 hours of continuous recording time is possible. A small acceleration-sensing unit used with the recorder can be mounted independently of the recorder. Although built principally for collecting statistical data on gusts encountered in scheduled airline operations, the instrument records data in a manner which permits many studies pertaining to airplane operations which have air speed, normal acceleration, and altitude as parameters.

Landing Loads

With the advent of thin wings for high-speed flight, the increased use of external stores, and the trend toward airplanes of larger size, a knowledge of the behavior of flexible wings during landing becomes increasingly important. An investigation of a model consisting of a hull in combination with a flexible wing was made in the Langley impact basin, and the data are reported in Technical Note 2343. These data substantiated a theoretical method for considering the effect of structural flexibility on the applied hydrodynamic force.

The development of retractable lifting surfaces for imparting favorable hydrodynamic behavior to streamlined hulls has shown a trend toward the use of comparatively flat surfaces which blend with the bottom of a fuselage. Data on the impact loads and energy absorption of heavily loaded flat surfaces when landed at various trims and flight-path angles are reported in Technical Note 2330.

The validity of the reduced-mass method of representing wing-lift effects in free-fall drop tests of landing gears has been investigated and the results are reported in Technical Note 2400. The behavior of a small landing gear in the reduced-mass drop tests was compared with results obtained in a drop test where wing lift forces simulating airborne impact were mechanically applied to the test specimen during impact, and with results obtained in free-fall drop tests with full weight. Values of landing-gear load factor and ratio of shock-strut energy to impact energy obtained from reduced-mass drop tests were in fairly good agreement with the results obtained from simulated airborne impacts. The values of impact period and shock-strut effectiveness were generally lower in the reduced-mass drop tests than in the simulated airborne impacts, while strut stroke and mass travel were generally greater in the reduced-mass drop tests than in the simulated airborne impacts. The free-fall drop tests with full weight produced excessive values of load factor, impact period, strut stroke, mass travel, and impact energy, but values of strut effectiveness were in fairly good agreement with those obtained in the simulated airborne impacts.

VIBRATION AND FLUTTER

Increased effort is being expended upon flutter studies for transonic and supersonic speeds. Unusual configurations are also being investigated in order to keep pace with design trends for these speeds.

Unsteady Lift Theories

Calculations have been made of the forces on aerodynamic bodies in unsteady motion based upon the classical equations governing acoustic disturbances. These calculations have been greatly expedited by applying techniques which were developed in recent investigations of steady state supersonic theory. The build-up of lift and pitching moments on slender, triangular wings and wing sections undergoing sinking and pitching motions were calculated for subsonic, sonic, and supersonic speeds. These results have been reported in Technical Notes 2256, 2387, and 2403. These transient responses provide the necessary information for the prediction of responses to oscillatory motions of arbitrary frequency and are therefore applicable to problems in airplane dynamics and flutter calculations.

Iterative Solution of Flutter

Existing methods of flutter analysis include the representative-section method, generalized coordinate methods, matrix methods, and operational methods. Wielandt has suggested an iterative transformation procedure which is well suited to the flutter problem and similar characteristic-value problems. Because both the original and the translated work of Wielandt are difficult to follow, an explanation of the iterative-transformation procedure is given in Technical Note 2346 and the application of the procedure to ordinary natural vibration problems and to flexure-torsion flutter problems is shown in numerical examples. It appears from this work that the method is of practical usefulness. Comparisons of computed results with experimental results and with results obtained with other methods of analysis have also been made.

Effect of Coupling Between Modes

In an analysis of flutter involving coupled vibrations, questions arise concerning the accuracy of using uncoupled modes or coupled modes, as the latter greatly complicate the analysis. An analysis of the Raleigh type based on coupled modal functions, was made for a wing with simulated engines, or tip tanks, representing a wing with high mass coupling. The wing considered was uniform, unswept, and high aspect ratio, and was mounted as a cantilever. The results of this analysis were compared with those of an analysis based on uncoupled modes as well as with experimental results. For the configurations studied, agreement with experimental data was obtained for both methods of analysis; therefore, the more complicated coupled-mode analysis may be unnecessary (Technical Note 2375).

Single Degree of Freedom Flutter

Beside the usual types of flutter involving coupled modes, the theoretical existence of a single-degree-of-freedom flutter has been indicated and is of interest in dynamic stability. Therefore it was deemed advisable to study the effects of some parameters affecting this single-degree-of-freedom oscillation. One such analytical study concerned the effect of Mach number and structural damping on single-degree-of-freedom pitching oscillations of a wing. Some experimental results were compared with theory and good agreement was found for certain ranges of an inertia parameter (Technical Note 2396).

Sound

Propeller noise has been a problem even at subsonic tip speeds; hence the proposed use of propellers operating at supersonic tip speeds has caused some concern because of the severity of the associated noise problem. Very little information is available which would allow a prediction of noise levels. Therefore sound measurements have been made for a two-blade propeller with a tip Mach number of 1.30. Sound spectrums were obtained at both subsonic and supersonic tip speeds, and the measured data were compared with calculations by the Gutin theory.

AIRCRAFT STRUCTURAL MATERIALS

Fatigue of Metals

The project on fatigue at Battelle Memorial Institute mentioned in previous annual reports has continued, and significant progress has been made in fulfilling the purpose of the program, which is to provide information sufficiently comprehensive to permit its application to design and to the estimation of fatigue damage. The materials being investigated in this program are 24S–T3 and 75S–T6 aluminum alloys and SAE 4130 steel. Results previously reported on unnotched specimens are contained in Technical Note 2324. Fatigue data on notched specimens over a range of stress concentration factors of 1.5 to 5.0 are the subject of several other reports. Those on stress concentration factors of 2.0 and 4.0 are in Technical Note 2389, and those on stress concentration factors of 5.0 are given in Technical Note 2390. Data have also been obtained on specimens having a stress concentration factor of 1.5. This range of stress concentrations is considered to be that of most importance in aircraft from the fatigue viewpoint.

In the investigation of the statistical nature of fatigue at Carnegie Institute of Technology during the past year, the statistics of the fatigue fracture curves and endurance limits were determined for SAE 1050 steel, annealed Armco iron, and SAE 4340 steel in the quenched and tempered and quenched and spheroidized conditions. The effects of metallurgical factors such as composition, heat treatment, and cleanliness on fatigue behavior were shown by a statistical analysis of the experimental results. From this work it has been concluded that inclusions play the dominant role in the fatigue behavior of these materials. In addition, some other aspects of the fatigue problem were studied, among which were the dependence of statistical variations in fatigue life on stress level in the fracture range, the statistics of the location of crack initiation, size effect, and understressing effects.

Axial fatigue tests were conducted at the National Bureau of Standards on flat sheet specimens of bare and alclad 24S–T3 aluminum alloy to determine the effect of frequency of loading on the fatigue strengths of these materials. The results of this investigation are contained in Technical Note 2231 and show that the fatigue strengths of the materials were slightly less when tested at 12 cycles per minute than when tested at 1,000 cycles per minute.

Another aspect of the fatigue problem was investigated at the Pennsylvania State College. The purpose of this project was to determine the influence of biaxial tensile stresses on the fatigue strength of 14S–T4 aluminum alloy when subjected to various ratios of biaxial stresses. These biaxial fatigue stresses were produced by applying simultaneously a pulsating internal pressure and fluctuating axial tensile load to a thin-walled tubular specimen. Fatigue strengths and S–N diagrams were obtained up to about 10,000,000 cycles for four principal stress ratios. The test results do not agree with any particular theory of failure but are sufficiently close to the maximum stress theory to permit its use in design.

Plasticity

In the 1950 annual report reference was made to an investigation at the Pennsylvania State College on the plastic biaxial stress-strain relations. The results of biaxial tensile stress tests on 75S–T6 material are published in Technical Note 2425, and the results of similar tests on 14S–T4 aluminum alloy were obtained during the past year. The main purpose of this investigation was to determine the validity of the plasticity theories and the correctness of the various assumptions made in these theories. To accomplish this purpose and to supplement the biaxial tensile test results the investigation was extended to include tests in which specimens were subjected to biaxial tension and compression. In these tests both constant and variable stress ratios were used. Although the data obtained do not agree with any of the current plasticity theories, it was found that the biaxial yield strength conforms most closely with the distortion energy theory.

For mathematical simplicity most plasticity theories assume solids to be isotropic and plastically incompressible. These assumptions fix the value of Poisson's ratio in the plastic range at 0.5. Physical considerations, however, make it apparent that the transition from the elastic to the plastic value of Poisson's ratio is gradual. An investigation of the variation in Poisson's ratio in the yield region of the stress-strain curve was completed by New York University during the past year. It is in this region that the transition from the elastic to the plastic value is most pronounced. This transition was studied experimentally by a systematic system of tests on 14S–T6, 24S–T4, and 75S–T6 aluminum alloys under simple tensile and compressive stresses along three orthogonal axes. The data obtained on Poisson's ratio in the yield region as well as values of the plastic dilatation for strain deviations up to 0.6 percent are given in Technical Note 2561.

Creep

In the design of structures required to operate at elevated temperatures, knowledge of the characteristics of materials at these temperatures is essential. One of the phenomena associated with elevated temperatures is that of creep, the time-dependent distortion of metals under stress. It is felt that a better understanding of creep phenomena will allow the more efficient use of materials in design. The experimental data available, however, are in general not sufficiently detailed nor do they cover a wide enough range in conditions to be effective for use in design, and although several theories have been advanced to account for creep behavior, these theories are not complete enough to be of much help. A study of the fundamental mechanism of the creep of metals has been initiated, therefore, at the Battelle Memorial Institute. Before proceeding with the experimental work, Battelle conducted a survey of the existing knowledge in the field. This survey, released as Technical Note 2516, treats the creep of both single-crystal and polycrystalline metals. The modes of deformation in short-time, low-temperature tests are considered, as well as the various theories which purport to explain the behavior of metals during creep. Battelle is now obtaining experimental data on the creep of 2S aluminum alloy over a wide temperature range and comparing these data with available theories. Should the data conform with none of these, efforts will be made to develop an appropriate theory to try to account for all the observed phenomena.

Stress Corrosion

The Armour Research Foundation in its investigation of stress corrosion has developed equipment which will permit observation and recording of the relative potentials of various regions near the surface of a metallic specimen during corrosion. By means of this equipment it is possible to locate the anodic and cathodic areas on a corroding surface and identify such areas with the corresponding metallurgical feature. Technical Note 2523 presents a description of this equipment and describes the techniques developed for the interpretation of the data obtained. The equipment is now being used to investigate the stress corrosion mechanism of a high-purity binary alloy, aluminum—4-percent copper.

Corrosion

The investigation of the corrosive properties of metals jointly sponsored by the NACA, Bureau of Areonautics, and the Air Matériel Command has continued at the National Bureau of Standards. The purpose of this investigation is to determine the rate of corrosion of materials used in aircraft when exposed to marine atmosphere and tidewater. During the past year data were obtained from exposure tests on galvanized steel stitched-aluminum alloys. These are reported in Technical Note 2299. The effect of hot dimpling on the corrosion of aluminum alloys 75S–T6 and alclad 75S–T6 was evaluated and results were also obtained from corrosion tests of magnesium alloy ZK60.

Hydrogen Embrittlement

A fundamental study was conducted at the Battelle Memorial Institute on the mechanism by which hydrogen enters metals, particularly aircraft steels, causing hydrogen embrittlement during chemical or electrochemical action. Several known methods of controlling the inlet and exit of hydrogen in steel were correlated with the known chemical behavior of atomic and molecular hydrogen. By means of this correlation it was found possible to select suitable reagents which significantly decreased hydrogen permeability and embrittlement of steel during cathodic pickling operations in dilute sulfuric acid. The same data show that the diffusion of hydrogen in steel and the freedom of exit of hydrogen are important in determining the extent of embrittlement and also that these phenomena are chemical in nature rather than mechanical.

Adhesives

In the manufacture of aircraft the bonding of sandwich panels, consisting of aluminum alloys bonded to various core materials, and the bonding of aluminum to itself by means of adhesives offers several important advantages over other methods of fastening, and there is considerable interest at the present time in such processes. There is a need, however, for an adhesive adequate for use at elevated temperatures. This led to the investigation at Forest Products Laboratory on the effects of temperature on the bond strength of joints fabricated with adhesives. The evaluation of the performance of commercially available metal bonding adhesives in the temperature range of —70° to 600° F. has been completed. The evaluation of the relative merits of the materials is based upon the data obtained from tensile tests of joints both when tested immediately upon reaching the test temperature and after several days' exposure at the test temperature.

Plastics

The investigation of the loss of strength of plastic glazing as a result of crazing has continued at the National Bureau of Standards. Since plastic glazing is used in the windows and canopies of airplanes, this property is of considerable interest to the aircraft industry. The meager information on the subject was expanded during the past year by two reports from the National Bureau of Standards. In one of these, Technical Note 2444, the loss in strength of several grades of polymethyl methacrylate due to stress solvent crazing is discussed. In this investigation tensile specimens were artificially crazed by applying benzene to the central portion of the specimen while it was under stress. Among the factors studied were the sheet-to-sheet variability of crazing specimens and the relative effect of a few large crazing cracks compared with more numerous finer cracks. Applying benzene to the specimens caused a loss of strength of approximately 30 percent in all of the materials.

An investigation was completed at the National Bureau of Standards on the strength of heat-resistant laminates up to 375° C. The flexural properties of samples of glass fabric laminates such as are used in radomes were determined for several loading cycles at elevated temperatures. The laminates tested were bonded with various resins, including unsaturated-polyester, acrylic, silicone, phenolic, and melamine types. Tests of a silicone resin laminate showed it to be superior to the other laminates in retention of flexural properties at temperatures of 250° C. or higher (Technical Note 2266). At temperatures of 300° to 325° C. this laminate retained at least 30 percent of its initial flexural strength and over 50 percent of its initial modulus of elasticity.

Materials Evaluation

The light weight, high-strength, corrosion-resistant, and favorable elevated-temperature properties of titanium have aroused interest in the possibility of using this material for aircraft structural applications. In order to indicate the potentialities of this material, an evaluation of titanium including comparisons with several other aircraft materials has been made for typical structural applications. The procedure developed for this purpose provides a general method for determining the structural efficiency of a material for a particular structural application (Technical Note 2269).

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OPERATING PROBLEMS

Investigations have been continued of the meteorological conditions adverse to the performance and safety of flight, means of accurately measuring air speed and static pressure at transonic and supersonic speeds, principles of design of aircraft systems for coping with natural icing conditions, and methods of improving aircraft safety. Research on atmospheric turbulence, aircraft ditching, and air speed measurement have been conducted by the Langley Aeronautical Laboratory, while studies of natural icing conditions, aircraft ice-protection systems, and aircraft crash fires have been conducted by the Lewis Flight Propulsion Laboratory. The Ames Aeronautical Laboratory has also done limited work in the field of aircraft icing. The work of the NACA laboratories has been supplemented by research conducted by several universities under contract to the NACA.

The practice of holding technical conferences with industry and military representatives was extended to the field of operating problems. A conference on some problems of aircraft operation was held at the Lewis Flight Propulsion Laboratory in the fall of 1950. The Committee on Operating Problems is responsible for the guidance of the operating problems research program. It is aided in specialized aspects of this program by its subcommittees, the Subcommittee on Meteorological Problems, the Subcommittee on Icing Problems, and the Subcommittee on Aircraft Fire Prevention.

AIRCRAFT OPERATION

Air Speed and Altitude Measurement

A systematic investigation of the static-pressure errors ahead of wings and fuselage noses of two low-wing airplanes was conducted in flight (Technical Note 2311). The variation of the static-pressure error with position of the static-pressure tube, located at several points from 0.25 to 2.0 chord lengths ahead of the wing tip and 0.5 to 1.5 fuselage diameters ahead of the nose, was determined over a speed range from the stall up to a maximum of 265 miles per hour. At low lift coefficients, the error decreased with increasing lengths ahead of the wing or fuselage, with variation in error over the lift-coefficient range being approximately the same for the 1½-diameter fuselage-nose installation and the 1-chord wing-tip installation.

For present-day high-performance airplanes having the capabilities of maneuvering to high angles of attack at supersonic speeds, the need has developed for rigid air-speed tubes which will measure total and static pressures correctly under these conditions. As a means of determining the optimum design of total-pressure tubes, a series of wind-tunnel tests has been conducted to determine the effect of inclination of the air stream on various types of total-pressure tubes over a wide range of angle of attack through the subsonic and supersonic speed ranges. Preliminary tests on 39 tubes at subsonic speeds are reported in Technical Note 2331. Subsequent tests of 20 of these tubes at supersonic speeds are reported in Technical Note 2261. The results of the tests showed that the tube which remained insensitive over the greatest range of angle of attack, both at subsonic and supersonic speeds, was a shielded total-pressure tube designed for end mounting on a horizontal boom. The range of angle of attack over which this tube remained insensitive (to within 1 percent of the impact pressure) was $\pm 41.5^\circ$ at subsonic speeds and $\pm 37^\circ$ at supersonic speeds. From the results of the tests of the other tubes, the effects of such design factors as external shape, internal shape, and configuration of total-pressure entry were evaluated, and the effect of Mach number on the performance of the various tubes was determined. Studies were also conducted of effects of position and airplane configuration on the measurement of air speed and Mach number in the transonic speed range. The applicability of using pressures on a cone as a measure of angle of attack at transonic speeds was also investigated.

Ditching

The investigation of the ditching characteristics of civil transport-type aircraft was completed with the studies of the behavior of the Convair-Liner. The recommended ditching procedures follow those for other transport types, touchdown being made at fairly high angle of attack with flaps down and landing gear up. The behavior depends upon the manner in which the flaps fail, the maximum deceleration being somewhat greater if the flaps rotate to neutral rather than being carried away.

AERONAUTICAL METEOROLOGY

Prediction of Low-Level Clear-Air Turbulence

Preliminary investigation of the meteorological variables associated with turbulence in clear air within the earth's friction layer led to the development of a simple empirical relation for estimating the intensity of the turbulence. The correlation of the observed gust experience of an airplane with various combinations of meteorological variables showed that a simple product form of the intensity of solar radiation and the average wind shear layer below the first discontinuity in temperature lapse rate gave very good results for conditions similar to those of the tests. This relation accounts for seasonal variations in turbulence intensity but, because of its simplicity, cannot discriminate between differences in turbulence intensity resulting from variations in flight altitude or diurnal variations in turbulence. The relationship has been established only for the limited conditions of terrain and meteorological situations during the flights in the vicinity of Wilmington, Ohio. Significant differences in these conditions will alter the relative importance of the meteorological variables considered.

Radar Detection of Thunderstorm Turbulence

Evaluation of the uses of airborne radar for detection of turbulent areas in thunderstorms was conducted by the Navy with the assistance of the Langley Laboratory staff. The presentation of areas of light rainfall and heavy rainfall on the radar PPI scope allowed preliminary correlation of the gust experience of an airplane with the indicated rainfall gradient. The limited results so far obtained indicated that possibilities of reducing the number and severity of the gusts likely to be encountered in a thunderstorm were good if the areas of high rainfall rate gradient were avoided.

Surface Wind Instruments

A wind-tunnel calibration of instruments for determining wind velocity and direction was conducted for the Signal Corps, United States Army. A three-cup anemometer was calibrated for measuring wind velocities up to 200 miles per hour. Two pressure-type combined wind-velocity and wind-direction indicators were also tested. One with four equally spaced orifices on the perimeter of a circular disk was tested up to 100 miles per hour, and another consisting of a pitot-static head mounted on a pivoted weather vane was tested up to 250 miles per hour.

AIRCRAFT ICING

Research is continuing at the Lewis Flight Propulsion Laboratory and the Ames Aeronautical Laboratory in an effort to establish the meteorological conditions that make up the icing cloud so that this knowledge may be applied toward the efficient design of aircraft ice-protection systems.

Characteristics of the Icing Cloud

The meteorological aspects of the icing cloud are being studied extensively in flight and laboratory investigations to determine what values of meteorological factors exist in the atmosphere and how these data can best be utilized to design efficient types of ice-protection systems for the various aircraft components. Tentative recommended values of meteorological factors to be considered in the design of aircraft ice-protection systems previously published (Technical Note 1855) have been supplemented with data collected by the NACA and other agencies during the 1948–49 and 1949–50 winter seasons and have been analyzed to present a method for the selection of design criteria. The data are summarized to give frequency of occurrence of icing conditions according to liquid-water content and drop size and further to indicate that statistical relations do exist between liquid-water content, mean effective droplet diameter, temperature, and pressure altitudes. A considerable amount of additional data is needed before a purely statistical analysis can be attempted; however, this accomplishment can be made possible only if the efforts to design suitable meteorological instruments are successful.

The Lewis Laboratory has developed and reported on a reliable pressure-type icing-rate meter that will automatically record icing rate, airspeed, altitude, and time in supercooled clouds. Evaluation tests on research and commercial aircraft indicate that the use of this instrument to collect a large amount of data for a statistical analysis is practical. The operation of the instrument is based on the creation of a differential pressure between an ice-free total-pressure system and a total-pressure system in which small total-pressure holes vented to static pressure are allowed to plug with ice accretion. At a fixed value of ice accretion, the differential pressure operates an electrical heater that de-ices the total-pressure holes. The resulting cyclic process varies with the intensity of the icing and serves as a measure of the icing rate. The simplicity of this operating principle permits automatic operation upon encountering an icing condition and relative freedom from maintenance and operating problems. The complete unit weighs only 18 pounds. Visual indications of the icing intensity are made available to the pilot by periodic flashing of a light on the instrument panel.

Another instrument previously developed as a cloud detector has been further investigated to provide a simple means for measuring liquid-water content in above- and below-freezing clouds. The instrument consists of a small cylindrical element so operated at high surface temperatures that the impingement of cloud droplets creates a significant drop in surface temperature. Preliminary calibrations of this instrument have indicated that improvements are expected to make it a reliable instrument for recording the important meteorological factor of liquid-water content.

Liquid-water content, droplet size, and temperature data measured in predominantly stratiform clouds during the last two icing seasons have been presented in

Technical Note 2306. The average liquid-water content of a cloud layer, as measured by the multicylinder technique, seldom exceeded two-thirds of that which could be released by adiabatic lifting. The horizontal and vertical extent of icing conditions and the relation of the existence of supercooled clouds to cyclonic areas and precipitation regions are indicated.

The Lewis Laboratory is continuing to make progress toward understanding of the fundamental processes involved in the formation of the icing cloud and in methods for its prediction. Part of this study has been a continuation of the investigation of spontaneous freezing temperatures of supercooled water droplets of the size found in the atmosphere. A statistical explanation of the previously reported investigation of spontaneous freezing temperatures of water droplets (Technical Note 2142) has been published in Technical Note 2234. The statistical theory is based on the presence of an assumed crystallization nuclei distribution suspended in the water and results indicate that small droplets may be supercooled to lower temperatures than the large droplets. The probable distribution curves of spontaneous freezing temperatures for water droplets of various sizes are given and compared with the experimental results.

Propeller Ice Protection

The Ames Laboratory has completed analytical and experimental investigations of the effect of ice formation on propeller performance (Technical Note 2212). The experimental measurements were made during flight in natural icing conditions, whereas the analysis consisted of an investigation of changes in blade section aerodynamic characteristics caused by ice formation and the resulting propeller efficiency changes. The results indicated that efficiency losses can generally be expected to be less than 10 percent with maximum losses as high as 20 percent to be expected only rarely. The effects of ice accretion on airfoil section characteristics at subcritical speeds, the effect of kinetic heating on the radial extent of ice formation, and the influence of the efficiency loss on the pilot's adjustment of engine and propeller controls are also discussed.

RESEARCH PUBLICATIONS

TECHNICAL REPORTS

No.

951. Use of Source Distributions for Evaluating Theoretical Aerodynamics of Thin Finite Wings at Supersonic Speeds. By John C. Evvard.
952. Direct Method of Design and Stress Analysis of Rotating Disks with Temperature Gradient. By S. S. Manson.
953. Attainable Circulation about Airfoils in Cascade. By Arthur W. Goldstein and Artur Mager.
954. Two-Dimensional Compressible Flow in Centrifugal Compressors with Straight Blades. By John D. Stanitz and Gaylord O. Ellis.
955. Application of Radial-Equilibrium Condition to Axial-Flow Compressor and Turbine Design. By Chung-Hua Wu and Lincoln Wolfenstein.
956. Linearized Compressible-Flow Theory for Sonic Flight Speeds. By Max. A. Heaslet, Harvard Lomax, and John R. Spreiter.
957. The Calculation of Downwash Behind Supersonic Wings with an Application to Triangular Plan Forms. By Harvard Lomax, Loma Sluder, and Max. A. Heaslet.
958. Laminar Mixing of a Compressible Fluid. By Dean R. Chapman.
959. One-Dimensional Flows of an Imperfect Diatomic Gas. By A. J. Eggers, Jr.
960. Determination of Plate Compressive Strengths at Elevated Temperatures. By George J. Heimerl and William M. Roberts.
961. The Application of Green's Theorem to the Solution of Boundary-Value Problems in Linearized Supersonic Wing Theory. By Max A. Heaslet and Harvard Lomax.
962. The Aerodynamic Forces on Slender Plane- and Cruciform-Wing and Body Combinations. By John R. Spreiter.

No.

963. Investigation with an Interferometer of the Turbulent Mixing of a Free Supersonic Jet. By Paul B. Gooderum, George P. Wood, and Maurice J. Brevoort.
964. The Effects of Variations in Reynolds Number between 3.0×10^6 and 25.0×10^6 upon the Aerodynamic Characteristics of a Number of NACA 6-Series Airfoil Sections. By Laurence K. Loftin, Jr., and William J. Bursnall.
965. The Longitudinal Stability of Elastic Swept Wings at Supersonic Speed. By C. W. Frick and R. S. Chubb.
966. Flutter of a Uniform Wing with an Arbitrarily Placed Mass According to a Differential-Equation Analysis and a Comparison with Experiment. By Harry L. Runyan and Charles E. Watkins.
967. Elastic and Plastic Buckling of Simply Supported Solid-Core Sandwich Plates in Compression. By Paul Seide and Elbridge Z. Stowell.
968. Investigation at Low Speeds of the Effect of Aspect Ratio and Sweep on Rolling Stability Derivatives of Untapered Wings. By Alex Goodman and Lewis R. Fisher.
969. Some Theoretical Low-Speed Span Loading Characteristics of Swept Wings in Roll and Sideslip. By John D. Bird.
970. Theoretical Lift and Damping in Roll at Supersonic Speeds of Thin Sweptback Tapered Wings with Streamwise Tips, Subsonic Leading Edges, and Supersonic Trailing Edges. By Frank S. Malvestuto, Jr., Kenneth Margolis, and Herbert S. Ribner.
971. Theoretical Stability Derivatives of Thin Sweptback Wings Tapered to a Point with Sweptback or Sweptforward Trailing Edges for a Limited Range of Supersonic Speeds. By Frank S. Malvestuto, Jr., and Kenneth Margolis.
972. The Effect of Torsional Flexibility on the Rolling Characteristics at Supersonic Speeds of Tapered Unswept Wings. By Warren A. Tucker and Robert L. Nelson.

No.

973. Flight Investigation of the Effect of Various Vertical-Tail Modifications on the Directional Stability and Control Characteristics of a Propeller-Driven Fighter Airplane. By Harold I. Johnson.
974. The Supersonic Axial-Flow Compressor. By Arthur Kantrowitz.
975. Small Bending and Stretching of Sandwich-Type Shells. By Eric Reissner.
976. Linear Theory of Boundary Effects in Open Wind Tunnels with Finite Jet Lengths. By S. Katzoff, Clifford S. Gardner, Leo Diesendruck, and Bertram J. Eisenstadt.
977. Frequency Response of Linear Systems from Transient Data. By Melvin E. Laverne and Aaron S. Boksenbom.
978. Method of Designing Cascade Blades with Prescribed Velocity Distributions in Compressible Potential Flows. By George R. Costello.
979. On Stability of Free Laminar Boundary Layer between Parallel Streams. By Martin Lessen.
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981. Theoretical Analysis of Various Thrust-Augmentation Cycles for Turbojet Engines. By Bruce T. Lundin.
982. Icing-Protection Requirements for Reciprocating-Engine Induction Systems. By Willard D. Coles, Vern G. Rollin, and Donald R. Mulholland.
983. Line-Vortex Theory for Calculation of Supersonic Downwash. By Harold Mirels and Rudolph C. Haefeli.
984. Method for Determining the Frequency-Response Characteristics of an Element or System from the System Transient Output Response to a Known Input Function. By Howard J. Curfman, Jr. and Robert A. Gardiner.
985. A Radar Method of Calibrating Airspeed Installations on Airplanes in Maneuvers at High Altitudes and at Transonic and Supersonic Speeds. By John A. Zalovcik.
986. The Reversibility Theorem for Thin Airfoils in Subsonic and Supersonic Flow. By Clinton E. Brown.
987. Equilibrium Operating Performance of Axial-Flow Turbojet Engines by Means of Idealized Analysis. By John C. Sanders and Edward C. Chapin.
988. Comparative Drag Measurements at Transonic Speeds of Rectangular and Sweptback NACA 65–009 Airfoils Mounted on a Freely Falling Body. By Charles W. Mathews and Jim Rogers Thompson.
989. Critical Stress of Ring-Stiffened Cylinders in Torsion. By Manuel Stein, J. Lyell Sanders, Jr., and Harold Crate.
990. An Analysis of Supersonic Aerodynamic Heating with Continuous Fuel Injection. By E. B. Klunker and H. Reese Ivey.
991. The Application of the Statistical Theory of Extreme Values to Gust-Load Problems. By Harry Press.
992. Theoretical Comparison of Several Methods of Thrust Augmentation for Turbojet Engines. By Eldon W. Hall and E. Clinton Wilcox.
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2303. Correspondence Flows for Wings in Linearized Potential Fields at Subsonic and Supersonic Speeds. By Sidney M. Harmon.
2304. Effect of Heat and Power Extraction on Turbojet-Engine Performance. IV—Analytical Determination of Effects of Hot-Gas Bleed. By Stanley L. Koutz.
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2310. Generalization of Boundary-Layer Momentum-Integral Equations to Three-Dimensional Flows Including Those of Rotating System. By Artur Mager.
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2313. The Effects of Mass Distribution on the Low-Speed Dynamic Lateral Stability and Control Characteristics of a Model with a 45° Sweptback Wing. By Donald E. Hewes.
2314. Effect of Quadratic Terms in Differential Equations of Atmospheric Oscillations. By C. L. Pekeris.
2315. Supersonic Lift and Pitching Moment of Thin Sweptback Tapered Wings Produced by Constant Vertical Acceleration. Subsonic Leading Edges and Supersonic Trailing Edges. By Frank S. Malvestuto, Jr., and Dorothy M. Hoover.
2316. Wind-Tunnel Investigation at Low Speed of Lateral Control Characteristics of an Untapered 45° Sweptback Semispan Wing of Aspect Ratio 1.59 Equipped with Various 25-Percent-Chord Plain Ailerons. By Harold S. Johnson and John R. Hagerman.
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2318. Full-Scale-Tunnel Investigation of the Static-Thrust Performance of a Coaxial Helicopter Rotor. By Robert D. Harrington.
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2320. Effects of Some Solution Treatments Followed by an Aging Treatment on the Life of Small Cast Gas-Turbine Blades of a Cobalt-Chromium-Base Alloy. I—Effect of Solution-Treating Temperature. By C. Yaker and C. A. Hoffman.
2321. Analysis of Temperature Distribution in Liquid-Cooled Turbine Blades. By John N. B. Livingood and W. Byron Brown.
2322. Creep of Lead at Various Temperatures. By Peter W. Neurath and J. S. Koehler.
2324. Fatigue Strengths of Aircraft Materials. Axial-Load Fatigue Tests on Unnotched Sheet Specimens of 24S-T3 and 75S-T6 Aluminum Alloys and of SAE 4130 Steel. By H. J. Grover, S. M. Bishop, and L. R. Jackson.
2325. Development of Magnesium-Cerium Forged Alloys for Elevated-Temperature Service. By K. Grube, R. Kaiser, L. W. Eastwood, C. M. Schwartz, and H. C. Cross.
2326. Two-Dimensional Subsonic Compressible Flows Past Arbitrary Bodies by the Variational Method. By Chi-Teh Wang.
2327. Fatigue Testing Machine for Applying a Sequence of Loads of Two Amplitudes. By Frank C. Smith, Darnley M. Howard, Ira Smith, and Richard Harwell.
2328. Method for Determining Pressure Drop of Monatomic Gases Flowing in Turbulent Motion through Constant-Area Passages with Simultaneous Friction and Heat Addition. By M. F. Valerino and R. B. Doyle.
2329. High-Temperature Protection of a Titanium-Carbide Ceramal with a Ceramic-Metal Coating Having a High Chromium Content. By Dwight G. Moore, Stanley G. Benner, and William N. Harrison.
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2331. Wind-Tunnel Investigation of a Number of Total-Pressure Tubes at High Angles of Attack. Subsonic Speeds. By William Gracey, William Letko, and Walter R. Russell.
2332. Analysis of the Effects of Wing Interference on the Tail Contributions to the Rolling Derivatives. By William H. Michael, Jr.
2333. Transient Aerodynamic Behavior of an Airfoil Due to Different Arbitrary Modes of Nonstationary Motions in a Supersonic Flow. By Chieh-Chien Chang.
2334. On Reflection of Shock Waves from Boundary Layers. By H. W. Liepmann, A. Roshko, and S. Dhawan.
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2339. Transonic Flow Past a Wedge Profile with Detached Bow Wave—General Analytical Method and Final Calculated Results. By Walter G. Vincenti and Cleo B. Wagoner.
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2343. Comparison of Theoretical and Experimental Response of a Single-Mode Elastic System in Hydrodynamic Impact. By Robert W. Miller and Kenneth F. Merten.

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2345. The Effect of an Arbitrary Surface-Temperature Variation along a Flat Plate on the Convective Heat Transfer in an Incompressible Turbulent Boundary Layer. By Morris W. Rubesin.

2346. An Iterative Transformation Procedure for Numerical Solution of Flutter and Similar Characteristic-Value Problems. By Myron L. Gossard.

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2349. Fluctuations in a Spray Formed by Two Impinging Jets. By Marcus F. Heidmann and Jack C. Humphrey.

2350. On the Second-Order Tunnel-Wall-Constriction Corrections in Two-Dimensional Compressible Flow. By E. B. Klunker and Keith C. Harder.

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2362. Torsional Strength of Stiffened D-Tubes. By E. S. Kavanaugh and W. D. Drinkwater.

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2383. On a Solution of the Nonlinear Differential Equation for Transonic Flow Past a Wave-Shaped Wall. By Carl Kaplan.

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2389. Fatigue Strengths of Aircraft Materials. Axial-Load Fatigue Tests on Notched Sheet Specimens of 24S–T3 and 75S–T6 Aluminum Alloys and of SAE 4130 Steel with Stress-Concentration Factors of 2.0 and 4.0. By H. J. Grover, S. M. Bishop, and L. R. Jackson.

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2398. Synthesis of Cyclopropane Hydrocarbons from Methylcyclopropyl Ketone. III—2-Cyclopropyl-1-Butene, *cis* and *trans* 2-Cyclopropyl-2-Butene, and 2-Cyclopropylbutane. By Vernon A. Slabey and Paul H. Wise.

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2408. Approximate Design Method for High-Solidity Blade Elements in Compressors and Turbines. By John D. Stanitz.

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2410. Analytical Investigation of Fully Developed Laminar Flow in Tubes with Heat Transfer with Fluid Properties Variable Along the Radius. By Robert G. Deissler.

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2414. An Experimental Determination of the Critical Bending Moment of a Box Beam Stiffened by Posts. By Paul F. Barrett and Paul Seide.

2416. Theoretical Study of Some Methods for Increasing the Smoothness of Flight through Rough Air. By William H. Phillips and Christopher C. Kraft, Jr.

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2423. Theoretical Aerodynamic Characteristics of Bodies in a Free-Molecule-Flow Field. By Jackson R. Stalder and Vernon J. Zurick.

2424. Flight Investigation of the Effect of Transient Wing Response on Wing Strains of a Twin-Engine Transport Airplane in Rough Air. By Harry C. Mickleboro and C. C. Shufflebarger.

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2435. Direct-Reading Design Charts for 75S–T6 Aluminum-Alloy Flat Compression Panels Having Longitudinal Extruded Z–Section Stiffeners. By William A. Hickman and Norris F. Dow.

2438. Heat Transfer to Bodies in a High-Speed Rarefied-Gas Stream. By Jackson R. Stadler, Glen Goodwin, and Marcus O. Creager.

2441. Optical Methods Involving Light Scattering for Measuring Size and Concentration of Condensation Particles in Supercooled Hypersonic Flow. By Enoch J. Durbin.

2443. The Similarity Law for Hypersonic Flow about Slender Three-Dimensional Shapes. By Frank M. Hamaker, Stanford E. Neice, and A. J. Eggers, Jr.

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2502. Examples of Three Representative Types of Airfoil-Section Stall at Low Speed. By George B. McCullough and Donald E. Gault.

2516. A Survey of Creep in Metals. By A. D. Schwope and L. R. Jackson.

2523. Rotogenerative Detection of Corrosion Currents. By Joseph B. McAndrew, William H. Colner, and Howard T. Francis.

2561. A Study of Poisson's Ratio in the Yield Region. By George Gerard and Sorrel Wildhorn.

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Citations to German reports in this list will use the following abbreviations where applicable:

ZWB—Zentrale für Wissenschaftliches Berichtswesen der Luftfahrtforschung des Generalluftzeugmeisters (German Central Publication Office for Aeronautical Reports).

FB—Forschungsbericht (Research Report).

UM—Untersuchungen und Mitteilungen (Reports and Memoranda).

No.

1241. Basic Differential Equations in General Theory of Elastic Shells. By V. S. Vlasov. From Prikladnaia Matematika i Mekhanika, Vol. 8, 1944, pp. 109–140.

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1258. Flight Performance of a Jet Power Plant. III—Operating Characteristics of a Jet Power Plant as a Function of Altitude. By F. Weinig. From ZWB, FB 1743/3, Nov. 1, 1943.

1260. Exact Solutions of Equations of Gas Dynamics. By I. A. Klebel. From Prikladnaya Matematika i Mekhanica, Vol. 11, 1947, pp. 193–198.

1261. On the Theory of the Propagation of Detonation in Gaseous Systems. By Y. B. Zeldovich. From Zhurnal Experimentalnoi i Teoreticheskoi Fiziki, Vol. 10, 1940, pp. 542–568.

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1272. Critical Velocities of Ultracentrifuges. By V. I. Sokolov. From Zhurnal Tekhnicheskoi Fiziki (U. S. S. R.), Vol. 16. No. 4, 1946, pp. 463–468.

1273. Resonance Sound Absorber with Yielding Wall. By S. N. Rzhevkin. From Zhurnal Teckhnicheskoi Fiziki (U. S. S. R.), Vol. 16, No. 4, 1946, pp. 381–394.

1276. Sideslip in a Viscous Compressible Gas. By V. V. Struminsky. From Doklady, Akademii Nauk (U. S. S. R.), Vol. 54, No. 9, 1946, pp. 769–772.

[1] The missing numbers in the series of Technical Memorandums were released before or after the period covered by this report.

No.

1278. General Solution of Prandtl's Boundary-Layer Equation. By W. Mangler. From Lilienthal-Gesellschaft für Luftfahrtforschung, Bericht 141, Oct. 1941, pp. 3–7.

1281. Unstable Capillary Waves on Surface of Separation of Two Viscous Fluids. By V. A. Borodin and Y. F. Dityakin. From Prikladnaya Matematika i Mekhanika, Vol. 13, No. 3, 1949, pp. 267–276.

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1283. Resistance of a Delta Wing in a Supersonic Flow. By E. A. Karpovich and F. I. Frankl. From Prikladnaya Matematika i Mekhanika, Vol. 11, No. 4, 1947, pp. 495–496.

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1289. The Development of a Hollow Blade for Exhaust Gas Turbines. By H. Kohlmann. From ZWB, UM 788, Dec. 1943.

1291. On Stability and Turbulence of Fluid Flows. By Werner Heisenberg. From Annalen der Physik, Vol. 74, No. 15, 1924, pp. 577–627.

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1305. On Ionization and Luminescence in Flames. By E. Sänger, P. Goercke, and I. Bredt. From original manuscript received June 17, 1949.

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1312. Calculation of the Bending Stresses in Helicopter Rotor Blades. By P. de Guillenchmidt. From Société Nationale de Constructions Aeronautiques du Centre, Rapport He3–0.03, Dec. 23, 1948.

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Part II—COMMITTEE ORGANIZATION AND MEMBERSHIP

The act of Congress approved March 3, 1915, establishing the National Advisory Committee for Aeronautics, as amended (U. S. Code, Supplement IV, title 50, sec. 151), provides that the Committee shall consist of 17 members appointed by the President, and shall include "two representatives of the Department of the Air Force; two representatives of the Department of the Navy, from the office in charge of naval aeronautics; two representatives of the Civil Aeronautics Authority; one representative of the Smithsonian Institution; one representative of the United States Weather Bureau; one representative of the National Bureau of Standards; the Chairman of the Research and Development Board of the National Military Establishment; and not more than seven other members selected from persons acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences." These latter seven members serve for terms of 5 years. The representatives of the Government organizations serve for indefinite periods. All members serve as such without compensation.

Hon. Donald W. Nyrop, Chairman of the Civil Aeronautics Board, was appointed by President Truman a member of the National Advisory Committee for Aeronautics under date of April 24, 1951, succeeding Hon. Delos W. Rentzel, who resigned from the Committee because of his appointment as Under Secretary of Commerce for Transportation.

In accordance with law, Hon. Walter G. Whitman was appointed a member of the Committee August 9, 1951, following his appointment as Chairman of the Research and Development Board. Professor Whitman succeeded Hon. William Webster, who resigned from the Committee in July, concurrently with his resignation as Chairman of the RDB.

Because of his retirement from the United States Air Force, the membership of Maj. Gen. Gordon P. Saville on the Committee was terminated July 31, 1951. General Saville was serving as Deputy Chief of Staff, Development, in the Air Force. Another termination of membership resulted from the resignation of Dr. Edward U. Condon as Director of the National Bureau of Standards, effective September 30, 1951. Successors to General Saville and Dr. Condon on the Committee have not been appointed.

In accordance with the regulations governing the organization of the Committee as approved by the President, the Chairman and Vice Chairman are elected annually, as are also the Chairman and Vice Chairman of the Executive Committee.

On October 12, 1951, Dr. Jerome C. Hunsaker was reelected Chairman of the NACA and of the Executive Committee, and Dr. Alexander Wetmore and Dr. Francis W. Reichelderfer were reelected Vice Chairman of the NACA and Vice Chairman of the Executive Committee, respectively.

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Mr. Robert Rosenbaum, Civil Aeronautics Administration.
Mr. I. E. Garrick, NACA Langley Aeronautical Laboratory.
Mr. Albert Erickson, NACA Ames Aeronautical Laboratory.
Mr. Samuel S. Manson, NACA Lewis Flight Propulsion Labora-Corp.
Dr. William E. Cox, Northrop Aircraft, Inc.
Dr. J. M. Frankland, Chance Vought Aircraft, United Aircraft Corp.
Mr. Martin Goland, Midwest Research Institute.
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Dr. Robert F. Mehl, Carnegie Institute of Technology.
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Mr. David G. Reid, Chance Vought Aircraft Division, United Aircraft Corp.
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Dr. T. L. K. Smull, Secretary.

Part III—FINANCIAL REPORT

Appropriations for the fiscal year 1951.—Funds and contract authority in the following amounts were appropriated for the Committee for the fiscal year 1951 in the General Appropriation Act, 1951, approved September 6, 1950, and the Second Supplemental Appropriation Act, 1951, approved January 6, 1951:

Salaries and expenses		$45, 750, 000
Construction and equipment of laboratory facilities:		
Funds to continue financing of fiscal year 1949 program:		
Langley Aeronautical Laboratory	$6, 000, 000	
Lewis Flight Propulsion Laboratory	4, 000, 000	
		10, 000, 000
Funds to continue financing of fiscal year 1950 program:		
Langley Aeronautical Laboratory	$2, 771, 988	
Pilotless Aircraft Research Station	478, 012	
Lewis Flight Propulsion Laboratory	1, 750, 000	
		5, 000, 000
Funds to start financing of fiscal year 1951 program:		
Langley Aeronautical Laboratory	$200, 000	
Ames Aeronautical Laboratory	300, 000	
Lewis Flight Propulsion Laboratory	1, 818, 000	
		2, 318, 000
Total appropriated funds, fiscal year 1951		$63, 068, 000

Contract authority for remaining obligations necessary to complete fiscal year 1951 program:	
Langley Aeronautical Laboratory	$2, 300, 000
Ames Aeronautical Laboratory	8, 700, 000
Total contract authority, fiscal year 1951	$11, 000, 000

Obligations incurred against the fiscal year 1951 appropriated funds and contract authority are listed below, together with the unobligated balances remaining on August 31, 1951. The figures shown for salaries and expenses include the costs for personal services, travel, transportation, communication, utility services, printing and reproduction, contractual services, supplies and equipment.

Salaries and expenses:	
NACA Headquarters	$1, 081, 842
Langley Aeronautical Laboratory	17, 631, 974
Pilotless Aircraft Research Station	803, 904
High-Speed Flight Research Station	$919.281
Ames Aeronautical Laboratory	7, 535, 318
Western Coordination Office	18, 485
Lewis Flight Propulsion Laboratory	16, 416, 186
Wright-Patterson Coordination Office	10, 424
Research contracts—educational institutions	779, 649
Services performed by National Bureau of Standards and Forest Products Laboratory	209, 501
Unobligated balance	343, 436
Total appropriated funds, salaries and expenses	45, 750, 000

Construction and equipment of laboratory facilities:		
Funds to continue financing of fiscal year 1949 program:		
Langley Aeronautical Laboratory	$5, 858, 400	
Lewis Flight Propulsion Laboratory	3, 999, 508	
Unobligated balance	142, 092	
		10, 000, 000
Funds to continue financing of fiscal year 1951 program:		
Langley Aeronautical Laboratory	$2, 755, 553	
Pilotless Aircraft Research Station	473, 863	
Lewis Flight Propulsion Laboratory	1, 708, 099	
Unobligated balance	62, 485	
		5, 000, 000
Funds to start financing of fiscal year 1951 program:		
Langley Aeronautical Laboratory	$198, 222	
Ames Aeronautical Laboratory	300, 000	
Lewis Flight Propulsion Laboratory	1, 676, 796	
Unobligated balance	[1] 142, 982	
		2, 318, 000
Total appropriated funds, fiscal year 1951		$63, 068, 000

Contract authority for remaining obligations necessary to complete fiscal year 1951 program:	
Langley Aeronautical Laboratory	$1, 497, 744
Ames Aeronautical Laboratory	3, 177, 786
Unobligated balance	[1] 6, 324, 470
Total contract authority, fiscal year 1951	$11, 000, 000

[1] These unobligated balances remain available for obligation in the fiscal year 1952.

Appropriation for the Unitary Wind Tunnel Plan Act.—Funds in the amount of $75,000,000 were appropriated in the Deficiency Appropriation Act, 1950, approved June 29, 1950, for the construction of wind tunnels authorized in the Unitary Wind Tunnel Plan Act of 1949 (Public Law 415, 81st Cong., approved October 27, 1949). These funds are available until expended. Allotments and obligations as of June 30, 1951, are as follows:

	Allotments	*Obligations as of June 30, 1951*
Langley Aeronautical Laboratory	$14,917,000	$6,440,860
Ames Aeronautical Laboratory	27,227,000	9,904,944
Lewis Flight Propulsion Laboratory	32,856,000	9,905,955
Total	$75,000,000	$26,251,759

Appropriations for the fiscal year 1952.—The major allotments of the funds appropriated for the Committee for the fiscal year 1952 in the Independent Offices Appropriation Act, 1952 approved August 31, 1951, are given below:

Salaries and Expenses		$49,250,000
Construction and equipment of laboratory facilities:		
Funds to complete financing of fiscal year 1949 program:		
Langley Aeronautical Laboratory	$372,800	
Lewis Flight Propulsion Laboratory	550,000	
		922,800

Construction and equipment of laboratory facilities—Continued	*Allotments*	*Obligations as of June 30, 1951*
Funds to complete financing of fiscal year 1950 program:		
Langley Aeronautical Laboratory	$3,493,524	
Lewis Flight Propulsion Laboratory	1,500,000	
		$4,993,524
Funds to continue financing of fiscal year 1951 program:		
Langley Aeronautical Laboratory	$1,283,676	
Ames Aeronautical Laboratory	4,500,000	
		5,783,676
Funds to completely finance fiscal year 1952 program:		
Langley Aeronautical Laboratory	$730,000	
Pilotless Aircraft Research Station	90,000	
High-Speed Flight Research Station	4,000,000	
Ames Aeronautical Laboratory	1,480,000	
Lewis Flight Propulsion Laboratory	350,000	
		6,650,000
Total appropriated funds, fiscal year 1952		$67,600,000